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# Science & Technology

## Europe/International

## BMFT Subsidy Plan for Microsystems Technology 1994-1999

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*JPRS-EST-94-027* CONTENTS *14 October 1994*

94WS0480A Bonn MIKROSYSTEMTECHNIK 1994-1999: PROGRAMM IM RAHMEN DES ZUKUNFTSKONZEPTES INFORMATIONSTECHNIK in German Jan 94 pp i-vi, 1-100

[Book: "Microsystems Technology 1994-1999: Program Under the Future Information Technology Concept," Federal Department of Research and Technology, Report on Public Work, Bonn, January 1994, 100 pages, ISBN: 3-88135-276-7, captioned phtographs omitted]

## Germany: BMFT Subsidy Plan for Microsystems Technology 1994-1999

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[FBIS Translated Text]

### Preface

Public discussion of how Germany's economic position can be safeguarded has brought to light the role of research and development [R&D] in the process of innovation. It originates in the joint endeavors of experts from academia and the private sector to identify strategic fields in which forward-looking technologies, R&D potentials, marketing opportunities for industry and public benefits coalesce.

I consider it my responsibility to encourage promising fields of research by supporting scientists, researchers and developers to convert basic into applied know-how. This calls for a high degree of adaptability and flexibility between research institutes and firms. It is my hope that on the part of government this program will contribute thereto.

Microsystems technology [MST] is one such strategic field whose applications will help shape the complexion of the twenty-first century. The many contributions to the discussion from scholars and business people in the course of drafting the existing program have demonstrated that. The growing interest and independent endeavors in other countries of the European Union [EU], the U.S. and Japan confirm this assessment by German experts.

Microsystems technology will impact our future in a special manner; it is directed toward the benefit of individuals. Research for the public spans the field from medical technology via traffic control systems to environmental technologies. The possibilities of improving production and process engineering will help the competitiveness of products manufactured in Germany.

Exploiting microsystems technology's manifold options constitutes a challenge for industry as a whole. Nevertheless, the existing program pays special attention to small and mid-size enterprises [SMEs], since they reach the limits of their effectiveness in the exploitation of new technological options quicker than large firms but they should not be cut off from technological progress.

Whereas sufficiently flexible and thematically broadly diversified support instruments are now available for the development of products, support for combined projects lies at the core of the existing program. In it firms and research institutes precompetitively formulate the scientific and technological inferences that in turn form the basis for the subsequent production development of prototypes. This type of cooperation reflects the multidisciplinariness of technological approaches and the need for risk sharing among firms. I realize that it is not simple and takes time to develop this kind of cooperation. Such efforts, however, are essential if the point is to keep Germany's mature industrial structure competitive for the future, even on a worldwide scale.

If, despite all methodical doubts, a worldwide comparison is demanded, Germany presently is, in fact, a member of the group on the cutting edge of microsystems technology. In recent years the effective potential of universities, institutes and industry has been developed to its full extent. The job now is to engender marketable products too from the persuasive successes of basic research and applied R&D.

The previous support focus was open to international cooperation. It is my hope that the present approaches to international cooperation can be expanded considerably more in the future since not only has microsystems technology been incorporated in the EU's program but a number of European countries have also engaged in intensified efforts in this field.

[signed] Dr. Paul Krueger
Federal Minister for Research and Technology

### 1 Challenges and Benefits of Microsystems Technology

#### 1.1 What is Microsystems Technology?

"It is as if, using tweezers, you wanted to sew a button on the bedding in the bedroom through the keyhole of the house door. What is more, the rooms are cluttered with countless pieces of furniture that you have to maneuver the tweezers around. And too bad for you if you knock something over."

That is how a neurosurgeon describes current difficulties in operating on the brain using conventional endoscopes. Due to the associated risks it is not possible to perform many necessary operations. Voyaging inside the human being is, on the one hand, the subject of visionary media and futuristic researchers around the world but it is also the point of departure for currently actual problems in the development of technology. For friendly and cost-effective medical diagnosis and therapy through the keyhole, as it were, there are at present a wide diversity of concepts for overcoming the indicated problems. Beginning with individual solutions for the improvement of existing instruments via active endoscopes all the way up to designs for self-sufficient mini-robots capable of observing and measuring as well as even operating are just some of the concepts noted. All those

approaches have one thing in common: they depend on miniaturization and built-in intelligence and therefore require microsystems technological solutions.

**Microsystems Mimic Nature in the Way They Function**

If sensors, signal processing and actuators in miniaturized structural shape are integrated into a total system in such a way that they are able to "sense," "decide" and "react," then one is dealing with microsystems. What is crucial here is that the functions occur autonomously. Sensors correspond to human sense organs, signal processing to the brain and actuators to the limbs.

Microsystems are made feasible by combining structurally miniaturized and functional microtechnologies such as film technologies from electronics, integrated optics, micromechanics or enzymes as biological identification components. The individual components (sensors, signal processing, actuators) are integrated through structural and linkage technologies. Systems architectures and signal processing designs underlie the integration of microtechnologies. Computer-aided tools for designing, simulating and testing enable complex product developments. In this way, MST constitutes the functional integration of separate microtechnologies by applying systems technologies to units (compare [cf.] Fig. 1.1).

Such technologies are described in detail in chapter four; also noted are the development activities that still need to be carried out for those technologies to be microsystems integrable in specific areas of application: they are each in different "stages of maturity." Those stages of maturity and the economic data, such as series size, attainable price, production costs, will determine the respective degree of integration a microsystem can realize.

Concomitant with development of the individual technologies consideration has to be given, early on, to the requirements stemming from economic implementability.

**Microsystems Technology Is a Component of Information Technology**

Economically and technologically, the most interesting areas of application for information technology presently commence with sensors acquiring real-world data, for example [e.g.], physical dimensions such as temperature, acceleration, pressure or the concentration of specific chemical substances and extend all the way to

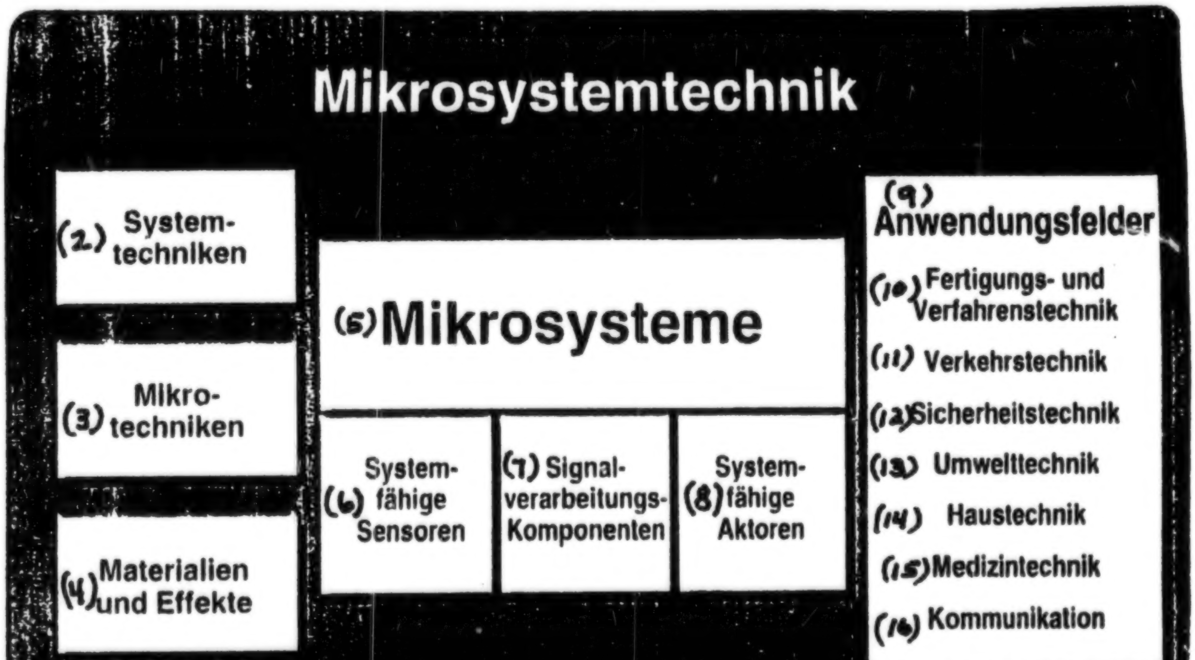


**Figure 1.1: Microsystems Technology Overview**

Key: 1. Microsystems Technology; 2. Systems technologies; 3. Microtechnologies; 4. Materials and effects; 5. Microsystems; 6. Systems-capable sensors; 7. Signal processing components; 8. Systems-capable actuators; 9. Fields of application; 10. Production and process technology; 11. Transportation technology; 12. Safety technology; 13. Environmental technology; 14. Household technology; 15. Medical technology; 16. Communications

the actuators' impact on the real-world. At present, microsystems technology stands at the threshold of technologically and economically promising development. Microsystems technology will be the key to innovation for the competitiveness of major branches of industry. Selective production processes depending on batch size will be critical for economic advantage. Mass-production cost advantages for microsystems can be enjoyed even with low sales figures if standardized components and a flexible structural and linkage technology is employed.

**Table 1.1 Examples of technologies for Microsystems Technology**

**Systems technologies:**

Structural and linkage technology;
Housing technologies;
Signal processing concepts;
Systems development methods;
Testing and diagnosis of microsystems;
Production methods;
Quality Assurance;

**Microtechnologies:**

Micromechanics;
Microelectronics;
Microthermics;
Micro- and integrated optics;
Optoelectronics;
Fiber optics;
Film technologies;
Semiconductor technologies;
Micromolding technologies;
Microfluidics;
Microacoustics;

**Materials and effects:**

Integration of chemical & biological materials & functions;
Ceramics technologies;
Piezo technologies;
Magnetostrictive technologies;
Membrane technologies;
Shaped-memory alloys;
Polymers

The following examples from current support in Germany and for possible future applications should illustrate the technological and economic potential of microsystems technology.

*Scientists usually associate the notion of "spectroscopy" with total German mark [DM] acquisition costs of five figures. Even now, microsystems technology affords us possibilities of blazing absolutely new trails here. The Karlsruhe Nuclear Research Center [Kfz] is working on development of a spectral microanalysis device whose chief components are a high quality spectrometer and micropumps in lithography, electroforming and molding [LIGA] technology (cf. section 4.2) plus chemical microsensors and electronic data processing. The external dimensions of that "micro-" spectrometer amount to a few millimeters while the reflection grating resolves structures in the submicrometer range. To study the medium—for example, samples from polluted bodies of water—a measurement vessel is filled using a micropump and a system of valves and then spectroscoped. By means of a photodiode strip integrated in the system the spectrogram is already converted into measured electrical values and preprocessed. Anticipated acquisition costs for it are more in the range of a few thousand DM.*

*Silicon micromechanics affords the possibility of a monolithic integration of micromechanical and microelectronic functional elements. In this manner a capacitive silicon pressure sensor element having signal processing complementary metal-oxide semiconductor [CMOS] microelectronics is developed on the same chip. It is possible from such sensor chips to develop smart pressure sensors for extremely diverse areas of application, e.g., in a handheld measuring device for checking combustion processes in chimney flues for energy-saving and environmentally friendly process optimization or in household technology. The objective was to lay the groundwork for making available application-specific integrated microsensors [ASIS] similar to the application-specific integrated circuits [ASICs] for micromechanical pressure sensors. That problem could only be overcome in a combine of technology and software developers plus chip, sensor and equipment manufacturers.*

*Basic research had to be closely integrated with applied aspects in the development of ASIS's. Simultaneously, the ASIS example already points to possibilities as to how MST solutions can be made available and manageable for a host of sensor manufacturers.*

*Currently under development is a microlaser in which diverse functional elements—integrated on a silicon substrate—work together in an extremely limited space. The beam from semiconductor diodes is bundled via miniaturized optical lenses and excites a solid-state crystal to emit laser beams having comparatively sizable optical yield. The geometric arrangement of the individual elements has to be realized with utmost accuracy and mechanical positioning aids are incorporated in the substrate. An integrated photodiode and a temperature sensor perform important functions in beam monitoring and temperature control on the chip. The microlaser affords a wealth of new and improved applications, such as in optical measurement technology (surface quality measurement, flow measurement), holographic measurement technology or even light detection and ranging [LIDAR] measurement technology (environmental protection, collision warning for ships, vehicles).*

## 1.2 Challenges and Benefits

### 1.2.1 Public Benefits

Microsystems entail the benefit of manifold improvements in the various technological and lifestyle sectors of society.

Over and above the applied fields so far found primarily of industrial automation, microsystems technological solutions can contribute towards safeguarding people's living conditions and existential well-being and towards a perceptible enhancement of the quality of life. As the following examples indicate, the positive effects can be seen even in the area of the public's day-to-day living.

Advances are anticipated in medical technology that will revolutionize present diagnostic processes and, above all, therapeutic processes and facilitate timely, sure identification and non-invasive treatment of diseases.

*The development and use of fiber-optic sensors enables, through the extreme miniaturization of the sensors, to acquire parameters that are not detectable using conventional processes. For radiation-therapy applications an implantable glass fiber dosimeter is under development whereby during radiation it will be possible to measure in real time the radiation load in the patient's body. This is particularly important if sensitive organs are located in the vicinity of the radiated area whose load has to be accurately tracked.*

*In the area of intensive medicine it is of major importance for the practicing physician to know the patient's blood parameters. A measuring system is under development for this purpose that can be housed in a catheter. The sensor chip contains a pressure sensor, a temperature sensor and signal-processing components including analog-digital conversion on a chip measuring 0.7 mm wide by 7 mm long.*

But improvements are also anticipated in everyday living;

- in energy-saving equipment for household technology,
- in inexpensive versions of safety systems for motor vehicles (antilock systems, airbags, standoff radar),
- in the work world (workplace pollution monitoring).

Furthermore, microsystems technology will open up new fields of measurement and control technology. Typical examples of applications are, for instance, the lean design of the Kfz engine and non-polluting furnace systems especially in the are of small plants and household fireplaces. Through application in industrial production, e.g., the integration of components directly in the process, considerable improvements can be realized in avoiding or reducing industry-generated emissions.

Effective protection of the environment calls for technologically measured detection and assessment of pollutants. The complex interactions between pollutants and nature place high demands on measurement technology and the assessment of possibly toxic and ecotoxic impacts on humans and on nature.

Microsystems technology affords the opportunity of definitely improving the technological measurement groundwork to realize environmental policy objectives at tenable costs. For this reason, in the future, it is conceivable there will be sensor systems for comprehensive monitoring of dumps if appropriate microsensors can be successfully developed on the basis of analytical chemistry. In this respect there are promising developmental approaches to miniaturized analytical systems using bio- or chemical sensors and to miniaturization of proven physical measurement processes like gas chromatography on a chip.

### 1.2.2 Opportunities for R&D Institutes

Non-university research institutes and universities dominate basic research activity. They clarify scientific problems as the basis for further stages in the innovation process.

Using microsystems, scientists have new possibilities for laying hold of new measuring methods to acquire knowledge, above all, in places where extreme conditions exist (space, sea floor) or measurement technology access is problematical for other reasons, e.g., in the entire microworld or in living organisms. Advances are also expected in coping with highly complex and enormous quantities of data (environmental measurements, meteorology).

*Biotechnological research, for instance, calls for accurate and careful manipulation of individual cells and at present contact-free electrical methods are under development for that purpose. Chambers and field electrodes are produced on a silicon substrate by means of coating and etching processes. Combined with a planar microstructured arrangement of electrodes on a rather broad substrate, an "electrical cage" is realized, in which dielectric particles, e.g., cells, can be moved about in a defined manner through application of alternating fields. That facilitates pinning down, transporting, splitting or even sorting of cells. In a similar dynamically balanced arrangement cells are rotated around. From the rotational behavior it is possible to derive inferences on the composition and the physiological status of living cells. There are interesting applications for this in test steps in biotechnological processes and in the use of cells as indicators in miniaturized analytical systems for environmental measurements or the testing of pharmaceuticals while avoiding animal experiments.*

Personnel need to be trained to expand appropriate research potential with expert and specialized knowledge in the area of microsystems technology. In the future, microsystems technology as a thematic "center of gravitation" will powerfully exert a major attraction on the world community of researchers. If Germany is attractive to elite researchers in the field of microsystems technology it may succeed in mobilizing the necessary personnel resources.

Universities, colleges and many non-academic R&D institutes have taken on the expertise challenge for the research sector: they are making personnel and equipment available for joint precompetitive R&D (cf. section

2.3.1). At many institutes microsystems technology is broached on the basic level but also with some applied relevance.

Two aspects, above all, are significant here, considering the insights gained thus far from industrial implementation of MST innovations. First, the demands for interdisciplinary cooperation increase with the combination of different separate technologies (e.g., micromechanics and biosensor technology). Next, even in the case of microsystems technological development projects having highly specific application, problems are generated that extend all the way back to basic research, e.g., materials compatibility or limits to the scalability of macroscopic processes and properties in the microrange.

The development of MST's options and the exploitation of economic opportunities calls for broad cooperation by academia and the private sector. This is attributable to the large number of problems needing resolution, the high degree of specialization and the required outlay. The necessary synergies can be engendered only through the interplay of the various agents. Such cooperation develops only gradually in the course of concretizing and further developing microsystems technology; the "cooperation network" still has gaps and even in the future it will not tighten without further glitches.

*Currently, for instance, there is a shortage of producers of components like valves, pumps, etc., for microfluid systems, among others. For medical technology manufacturers the technology for this is too costly and the necessary know-how is not available. On the other hand, the potential micromechanics producer has to ensure adequate piece numbers in production and endeavors, e.g., to design a microvalve design for various applications. Even this aspect speaks to a strategically oriented grouping of a number of users already in the early phase of development under an umbrella theme.*

### 1.2.3 Opportunities and Challenges for Industry

For industry, microsystems technology, on the one hand, holds options for future markets and, on the other, considerable requirements for innovative management.

#### Microsystems Technology as a Factor in Worldwide Competition

European and German industry in particular, with its highly developed applied know-how, occupies a good position in the international context in some MST technologies and, as a result, favorable conditions at the outset for safeguarding competitiveness.

The other industrial countries too have recognized the importance of MST. In Japan and the U.S., above all, manifold efforts have been made, by integrating industrial firms, to realize research results that can be turned into innovative products (cf. section 2.6).

#### Microsystems Solutions Break Through Major Markets

MST's technological options will be turned into applications and successful market development on the basis of the following mechanisms:

- MST components, e.g., microsensors, microactuators and signal processing, will continue to create autonomous market segments with considerable growth potential. Worldwide, microsensor markets by themselves are projected to total in the two-figure billions with sizable growth rates (cf. section 2.6.4).
- Microsystems will replace conventional systems solutions if they are offered at clearly lower costs and in greatly reduced structural dimensions. If such a substitution is feasible, MST will also determine the competitiveness of the user; economically, it will include major branches like machine building and vehicle manufacturing.
- MST will generate wholly new, original products that will enable hitherto unrealizable performances and be able to realize corresponding market volumes. This can be anticipated, e.g., in medical technology.

MST is a very recent field of technology and there are still no official statistics available for it. Instead, for Germany, for the first time, data were assembled on turnover for information technology products in the measurement and control technology sector that are produced using at least one microtechnology [MT] product (cf. table 1.1)[1]. In 1990, turnover totaled nearly DM16 billion at those firms that have at least one complex microtechnology (excluding ASICs development tools and surface assembly technology). That turnover was mainly realized by approximately 600 electrical engineering firms. But even at more than 400 firms from the precision mechanics, optics, timepieces, office and data technology branches plus machine building, MT products are now playing a role in turnover wherever information processing is crucial for the production function. As is to be expected with new technologies, the larger firms currently have the upper hand in turnover.

#### Increased Turnover Expected in Upcoming Years

To be able to provide reference points for the magnitudes of turnover growth, computer modeling was done for the years 1990-2000 (see figure 1.9). The following variations served as starting points for it:

*Status quo variation: Nearly [ca.] 90 percent of the 1,700 firms in Germany (original laender) that intended to use microtechnologies in upcoming years, based on a survey, are doing so too; with MT products they will in the future realize the same percentage of turnover as current MST firms. Total turnover of MT products will then rise by nearly one percent per year to DM17.9 billion in the year 2000.*

*Dissemination variation: In addition to the firms mentioned in the status quo variation, a further 30 percent of the 6,000 firms that are able potentially to use MST from*

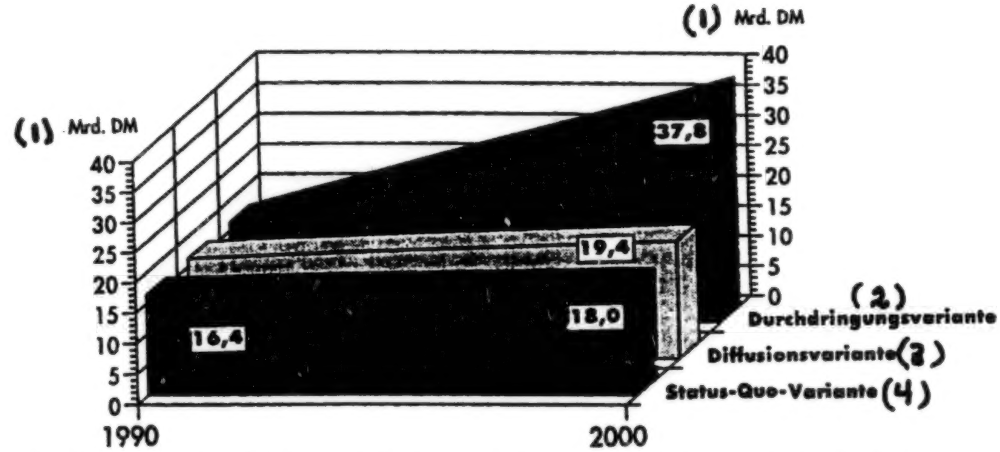


**Figure 1.9: Computerized model of growth in turnover of German firms' information technology products in the measurement and control technology sector that were produced using at least one microtechnology; sources: GIB 1990 and 1991 surveys, Stabua 1990, VDI/VDE-IT [VDI—Association of German Engineers, VDE—Association of German Electrical Engineers, IT—computer technology] in-house projection;**

Key: 1. Billions of DM; 2. Penetration variation; 3. Dissemination variation; 4. Status quo variation

*the vantage point of their product spectrum will decide to do so. As a result, MT turnover will increase a total of 1.7 percent per year to DM19.4 billion.*

*Penetration variation: Even the current 2,700 MST firms still have products on their palette that can be modernized in the future by the use of MST; in 1990, the turnover penetration of those firms with MT products was nine percent on average. It is assumed that this value will increase until the year 2000 to nearly 20 percent. This effect will mostly contribute to the future increase in turnover of MT products. Cumulatively with the other two variations, MT turnover will increase annually by nearly 11 percent to DM37.8 billion in the year 2000.*

This computerized model is conservative in its assumptions; actually expected effects on the market therefore will be somewhat greater than the projected values. Moreover, the impacts of any actual total economic growth were omitted. If two percent per year is the assumption, then turnovers of MT products in measurement and control technology will increase correspondingly to DM21.5 billion in the status quo variation, to DM34.0 billion in the dissemination variation and to DM45.5 billion in the penetration variation.

**MST Market Opportunities Will Not Develop Automatically**

To develop the market opportunities projected in the model variations, technological leaps at SMEs and intensification of current activities by those firms that have already engaged in MST early on, are a basic requirement. Currently, it is, above all, surface assembly technology and ASICs development tools that are widely processed while the very critical and still hardly tested MST technologies can be found in only a small number of large firms. In particular, the majority of SMEs presently still are not exploiting the more complex MST technologies.

**Interplay of All Partners**

The development and exploitation of MST will result from the interplay of all partners from research and industry across national borders: the requirements for technological specialization, financial resources and personnel are so high that the key to a commitment to MST that promises to be economically successful is strategically planned cooperation. In that context the individual partners assume a different part depending on their respective strengths:

- SMEs with their customer proximity in specialty markets will more easily contribute their MST components systems and engineering know-how, that can be developed and produced on the level of hybrid integration. They will continue to develop their technological competence in cooperation with universities and non-academic research institutes.
- Large firms will play a major role in technology development. They are more likely to concentrate on products for mass markets, for the production of which they will have to introduce extremely expensive production processes, e.g., monolithic integration.

This division of labor in MST renders cooperation necessary on different levels. So, in some MST fields of technology, large industry will follow the path of international cooperation, extending all the way to strategic alliances designed for the long term. Only in this way will it be possible to shoulder the sizable cost of development

and assure the market basis for full use of the required costly facilities. With such dimensions, the development of MST points beyond the possibilities of national research and technology policy to supranational activities such as those emerging, for instance, in the EU (cf. section 2.5).

Even the large firms face the challenge of engaging in cooperative activities with other firms that will enable them to offer components or technological services to be able to better utilize existing resources in development and production.

#### 1.2.4 Social Interests and Basic Conditions

Microsystems make it possible decisively to improve the technological groundwork for fulfilling responsibilities in the context of official concern. Progress can be expected especially in the areas of environmental protection, transportation infrastructure and medical care. Simultaneously, new market potentials will develop for industry as a result.

Regulations can be adjusted if, e.g., new pollutants can be measured using new technologies and even smaller concentrations can be detected or more economical systems for sophisticated monitoring become available.

The use of the available road system can be made more efficient through use of MST for smart traffic control systems. However, in that context, data protection issues too have to be addressed.

In any event, the possible risks of every technological potential have to be considered—especially if it may have far reaching impacts on the conditions for human life; only then, on the basis of traditional TA, will it be possible opportunely to take advantage of design options. Public discussion will enable a broad social consensus and extensive acceptance of MST to be assured. Topics for discussion will surely include:

- Changing demand for training and continuing education
- Exploiting new possibilities for workplace design
- Designing "human interfaces" for technology among developers and users taking into consideration the insights from industrial science
- Environmental impacts in development, production, use an d disposal of MST components
- Ethical and safety aspects in the introduction of new medical technologies.

## 2. The Arena for MST Support

### 2.1 What Goals Has the BMFT Pursued with Current Support for MST?

In the first MST support focus for 1990-1993, the BMFT initially pursued the following goals that are to be recalled in no particular order:

—Where MST leads to an expectation of synergistic effects, all parties should strive for coordination in formulating and brokering its technologies.

—Support of precompetitive, industrial combined projects, in connection with MST, should close technological and organizational gaps that have so far countered use of MST for product development.

—Indirect-specific support should, on the basis of the development of miniaturized and smart systems, help firms develop a systems-technology oriented culture of innovative management and intensify interrelated company networks as well as those among firms, research institutes and transfer centers.

—With the support of technology transfer, firms should be informed of the insights of technological developments, especially their readiness for application as well as regarding MST-relevant experiences in innovative management, and active mutual contacts for cooperation by firms and between firms and research institutes should be arranged.

After approval of the support focus, German unification entailed a further, very important goal: research institutes and firms in the accession area were to be afforded the opportunity to contribute their potential to the total development of MST.

### 2.2 Experiences from Current Support

#### 2.2.1 Synergistic Effects

For MST it was necessary to bring the parties from all sectors—from research through industry to advanced training institutions—into contact with one another. With its manifold information and communication activities, the support focus strove for a process of coordination and partially organized it. It was also possible, apart from any financial support, for impetuses to be given in the area.

Large technology concerns have championed the MST theme for their future and will have parts of their business activity in MST in the future. But small, specialized high-tech firms too are busy winning a market for themselves in MST, e.g., as technological service suppliers.

**Associations of Specialists Adopt MST**

Some associations of specialists have set up MST committees to be able to inform their members comprehensively about future development. For example, the VDE/VDI Microelectronics Society (GME) has numerous activities for MST and was the first specialized society to create an independent sector. Other examples followed on this: e.g., the Transducers Association (AMA) has instituted a specialized MST committee. As a result of the change in the existing boundaries among areas of

specialization, the former VDI/VDE Society for Precision Mechanics has expanded the range of its MT themes, e.g., in medical technology.

Hitherto the MST protagonists have created structures in their specialized associations in order to organize their interests. In contrast, there has still been little development of:

- any response to MST in the applications-oriented sectors of MST (machine building, environmental technology, etc.),
- the dialogue between developers and users of MST and authorities setting the framework conditions and regulations in the fields of application.

**Training and Continuing Education Reacts to MST**

Suppliers of continuing education have been sensitized to MST by having been informed on this new field and its diverse technological and business science aspects. With development of the MST continuing education suppliers' database, set up at the VDI-VDE-IT, they were encouraged to better coordinate their MST activities. Furthermore, contact between suppliers and consumers of continuing education for MST has been intensified through active marketing of the continuing education database offer.

Since the next generations of qualified employees will require special MST know-how, more than 15 universities and colleges have instituted or are far along in planning for MST courses and curricular foci or chairs. MST contents are increasingly being incorporated into courses like physics, electrical engineering and machine building. Even independent MST courses are being offered—e.g., at the universities of Freiburg, Ilmenau, Bremen, Hannover and the colleges in Berlin, Luebeck, Regensburg and Furtwangen. In Hamburg the path is being blazed for an "MST model course" at the TU [technical universities]. For many years now at Halle and Magdeburg, training and continuing education institutes have successfully engaged in the field of MST.

Major FRG firms active in the MST field project the demand for academically trained engineers oriented towards MST at five to 20 percent of the total demand for scientists and engineers. Given the current ca. 6,000 qualifying examinations annually in the subjects of electrical engineering and physics, that means 300-1,200 academically trained engineers per year for MST[2].

A panel on "Coursework incorporating MST," set up by the GME and the VDI/VDE-IT, is endeavoring to harmonize the curricula and university activities. In other European countries too, MST training activities have emerged.

**Producer-Consumer Dialogue Commences**

In an interdisciplinary field like MST, it is important for hitherto separated areas of specialization to work together; individuals who will extract possible commonalities in the themes also have to be brought together. For example, until now surgeons and other physicians have had hardly any contact with MST and micro-optics technologists. In medical technology new dimensions are opening up in minimally invasive therapy using MST and this can be developed only through the dialogue of such groups. Under the MST support focus, discussion groups have been organized on this as well as in environmental technology.

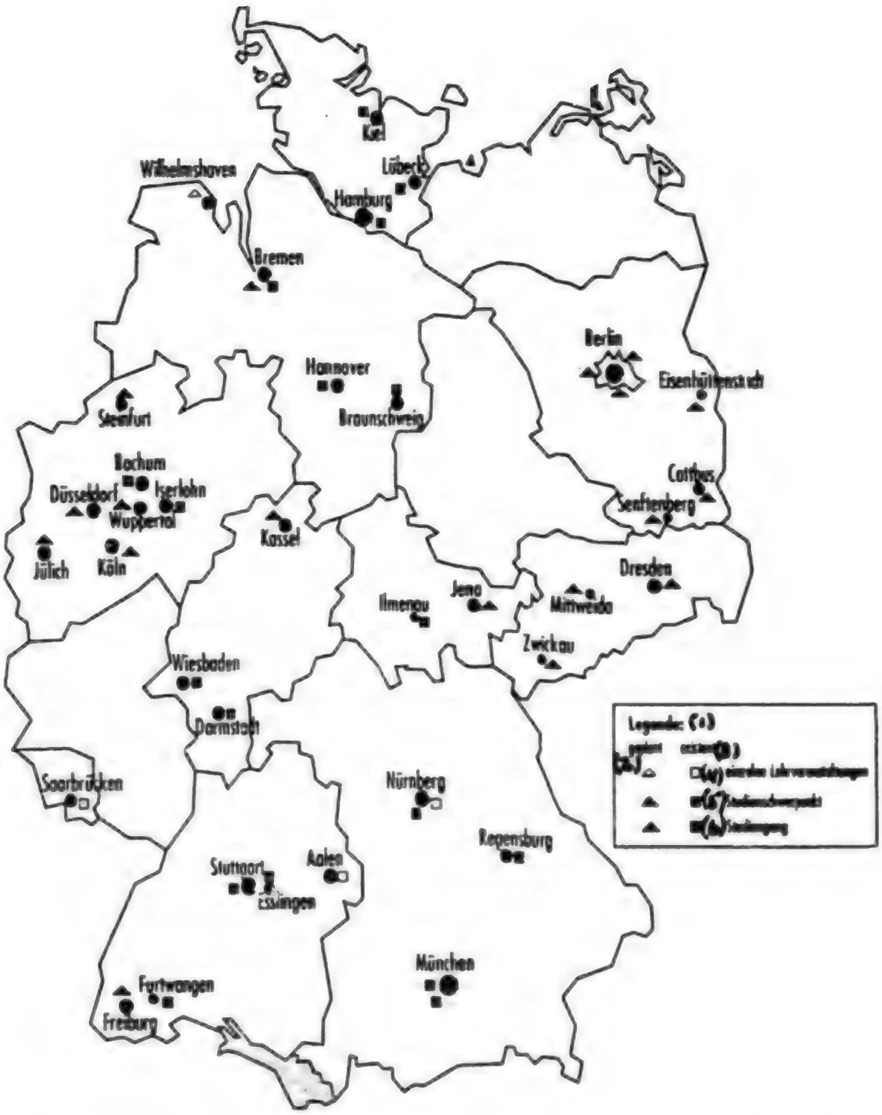


**Figure 2.1: MST courses offered at German universities; Source: VDI/VDE-IT, cutoff date, 31 December 1993**

Key: 1. Legend; 2. Planned; 3. Actual; 4. Independent educational establishments; 5. Course foci; 6. Curriculum

### 2.2.2 Closing Technological and Organizational Gaps

Precompetitive industrial combined projects should help close technological and organizational gaps that until now have hindered the widespread use of MST for product developments in firms. Combined projects could therefore have very different subordinate goals;

- Systems capability: adaptive development of separate MTs and systems technologies aimed at improving the systems capability of such technologies
- Manageability for SMEs: adaptive development of separate MTs and systems technologies to render them usable for SMEs
- Systems technology development: continued development of systems technologies for use in designing and producing microsystems solutions
- Model MST solutions: development of prototypes as examples of advanced MST solutions in selective fields of application
- MTs for service suppliers: continued development of process technologies to a level of readiness that enables offering them as technological services for MST processes

- Cross issues: development of solutions as examples for cross issues like standardization, quality assurance, qualification
- Basic industrial research: R&D on selective separate MT problems to ensure medium-term MST options They should develop a new or improved understanding of the laws of science and technology and their application.

**Applied Orientation Is the Right Way**

In such combined projects partners from research and industry worked jointly on the solution of technological problems. The partners contributed to each project their respective strengths reflective of their competencies and capabilities. That structure is a solid basis for the rapid transfer of research results to industrial practice. Even the partners from research welcome the applied orientation of MST projects.

From 1990 until the end of 1993, 48 combines were initiated entailing 300 supported subprojects. The approved projects were selected and further developed from more than 300 ideas and outline plans. Project selection especially targeted active implementation of the goals formulated in the program and filling in the gaps that have become evident in MST. Financial resources for the support were used up more quickly than anticipated; in the spring of 1992, therefore, a halt was called to the receipt of new designs or applications.

**Even SMEs Perform Precompetitive Activities**

The heavy participation of SMEs in precompetitive technological developments needs special emphasis: for example, 99 of the 163 industrial subprojects were worked on by firms with less than DM50 million in annual turnover. As a result, small firms are participating in combined research at a rate hitherto judged unrealizable. This has empirically contradicted the expressions of skepticism that could be heard at the outset of the support activity.

Concurrently, support practice matches the final recommendation of the German parliament's committee on research, technology and TA, dated 24 October 1992[3], providing enhanced support alternatives for SMEs targeting introduction of information and communication [IuK] technologies.

Firms having more than DM1,000 million in turnover have a 12-percent share of total combined research funding, equivalent to 26 percent for industrial recipients of the funding. Participation in the development process together with other partners from academia and industry so greatly interests some large firms that they join in work on the projects even without financial support; some also even make an additional financial contribution to finance the other partners of a combine.

The second largest participating group, after firms with less than DM50 million in annual turnover, comprised the university institutes. Those possessing the most advanced technological equipment are able to play a major role in the projects. Coordination between universities and the partners from industry is beneficial in the supported subprojects especially if the industrial partners in the combines contribute to the financing of the research institutes' project activities.

The average number of participants in the combined projects amounted to seven. That was determined on the basis of a few large projects. Therefore, e.g., the development of systems architectures, design tools, initial standards or reliability tests requires the consensus of a representative group of users from the outset. Special value was also attached to the participation of firms and research institutes from the NBL in the combines.

All of MST's technological thematic fields were worked on with development and linkage technology and treatment of systematic aspects foremost. The second experiential report on combined activity[5] indicates the type of contributions the combined projects make to the thematic fields. All MTs, however, still continue to manifest a high demand for R&D in terms of being combined into systems[6]. Systems technologies themselves will be the focus of intense interest in the future for being able optimally to design microsystems by respective function and series dimension. In any case, in the course of working on the program, there was an awareness that the problems emerging in connection with the production technology for MST products can be solved only as a whole. Product development, production technology and production management have to be viewed as a unit. Only through simultaneous engineering of research, development and production technology is it possible to keep product origination time in connection with the precompetitive combined projects in tenable relation with the market lag of a product. An intensive dialog between production designers and those developing the MST is essential for efficient exploitation of MST. The production technologies for microsystems being striven for can be realized only if existing incompatibilities among the separate highly developed technologies can be overcome.

Problems of innovative management and qualification that play a sizable part in industrial implementation of MST have hitherto been dealt with only slightly in combines as a cross-theme. This may also be due to the fact that the players who are active in the precompetitive area do not have this overarching problem at the focus of their research activity.

**Combines Create Stable Networks**

MST systems capability consists especially in the integration of separate sophisticated technologies. As a rule, the technological competence for this does not reside with any individual firm or institute. For this reason exceptional significance is to be attached to intensive

| | (1) Bewilligte Teilprojekte | | Bewilligte Zuwendungen (2) | |
|---|---|---|---|---|
| Unternehmen nach Umsatz (Mio DM) (6) | (3) Anzahl | (4) Anteil in % | (5) Mio DM | (4) Anteil in % |
| (7) bis < 50 | 99 | 33 | 54,0 | 25 |
| 50 bis (7) < 100 | 5 | 2 | 3,1 | 1 |
| 100 bis (7) < 200 | 8 | 2 | 7,0 | 3 |
| 200 bis (7) < 500 | 15 | 5 | 7,4 | 3 |
| 500 bis (7) < 1000 | 10 | 3 | 5,1 | 2 |
| > 1000 | 26 | 9 | 25,9 | 12 |
| zusammen (8) | 163 | 54 | 102,5 | 47 |
| darunter NBL (9) | 38 | 13 | 18,2 | 8 |
| (10) Forschungseinrichtungen: | | | | |
| (11) Universitäten, Fachhochschulen (12) | 85 | 28 | 69,9 | 32 |
| FhG-Institute (13) | 21 | 7 | 22,2 | 10 |
| Sonstige (14) | 31 | 10 | 23,7 | 11 |
| zusammen (8) | 137 | 46 | 115,8 | 53 |
| darunter NBL (9) | 46 | 15 | 30,2 | 14 |
| Insgesamt (15) | 300 | 100 | 218,3 | 100 |

(16) Basis: 48 Verbundprojekte mit insgesamt 300 geförderten Teilvorhaben.
Stand: 31.12 1993 (17)

**Table 2.1: Combined research: 1990-1993 MST support focus**

Key: 1. Approved subprojects; 2. Approved funding; 3. Number; 4. Share in; 5. Millions of DM; 6. Firms on the basis of turnover (millions of DM); 7. Up to; 8. Subtotal; 9. Including new laender [NBL]; 10. Research institutes; 11. Universities; 12. Colleges; 13. Fraunhofer Society [FhG] institutes; 14. Other; 15. Grand total; 16. Basis: 48 combined projects involving a total of 300 supported subprojects; 17. Cutoff date: 31 December 1993

cooperation among the players for continued development of MST. The interlinkage of partners from research, academia and industry was especially stimulated and strengthened by the combined projects: more than half of the combined participants plan to cooperate even outside of the supported project; hence, not only are there increased opportunities for success in other supported projects for precompetitive R&D but it has helped basically to develop long-term research relationships that will continue to exist without government support.

Implementation of the results—e.g., in status seminars on current projects—met with widespread interest. Combines are an effective instrument for technology transfer, both inside and outside of the group of participants, if in the future there is even better success in working on the targeted results and offering them to potential users in such a way that they can latch onto them for further activities on customary market terms. Implementation of active dissemination of the results is already starting with the establishment of a work program emphasizing marketing and the formulation of the

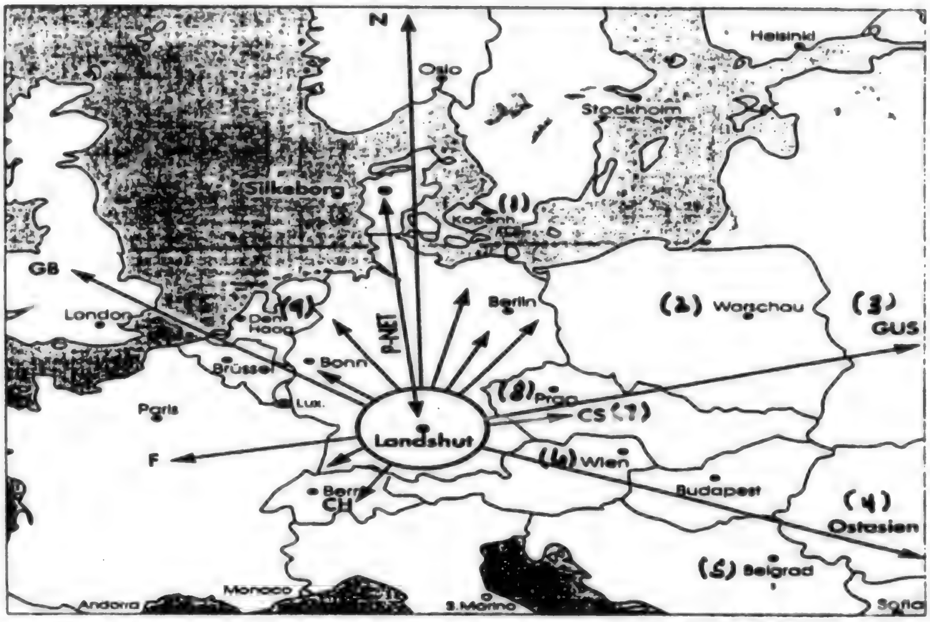


**Figure 2.3: Combines create networks as evidenced in the example of the GENIS combined project**

Key: 1. Copenhagen; 2. Warsaw; 3. CIS; 4. East Asia; 5. Belgrade; 6. Vienna; 7. Czechoslovakia; 8. Prague; 9. The Hague

framework conditions for cooperation in cooperative agreements and the various interests also have to be considered—especially the interests of the partners that make a sizable contribution of their own.

*In the combined project "Basic Developments for the Networkability of a Family of Smart Sensors/Actuators in MST" (GENIS), MST solutions were formulated over a three-year period by six mid-size firms in cooperation with three institutes and they are even now capable of application to many products in agriculture.*

*Development activities are being based on technological studies for miniaturization of field-bus capable sensors for road, temperature and moisture measurements, for P-NET field bus interfaces and for wireless communication via the bus.*

*In the course of the cooperation the combined partners developed manifold contacts and cooperative relationships surrounding the project with numerous firms and institutes inside and outside of the country. Those include contacts and cooperative activities in the Commonwealth of Independent States [CIS], the Czech Republic, Norway and even as far abroad as Southeast Asia. The technology transfer center of the college in Landshut is to be considered the hub of the activities with lectures, seminars and workshops on the combined results being offered to interested users.*

### 2.2.3 Improvement of Innovative Management

Indirect-specific support was supposed to improve the groundwork at firms with an annual turnover of up to DM1,000 million for long-term successful innovative management so that they could benefit from MST's potential. That is why even non-technological aspects like organizational development, qualification and cooperation were included in the support.

The support target was the exploitation of new technological processes and design methodology in the development of MST components: sensors, actuators and signal processing as well as the combination of MTs.

**Indirect-Specific Support Quickly Used Up**

The measure was so well received that as early as March 1991 the volume of applications equaled the available funding. Nearly 15 percent of legitimate applicant firms in the original laender were reached thereby while for firms from the new laender there was only a little time left between German unification and the expiration of the program to participate in the activity. What is more, they faced the problem of having to finance on their own the lion's share of the project costs that was not covered by the subsidy.

The support mostly benefited SMEs. More than 75 percent of the funding went to firms having less that DM50 million in annual turnover.

Three fourths of all approved development projects targeted either the development of a signal processing component or the development of microsensors/-actuators with market-available sensor/actuator elements. Such developments could be supported with a

| Unternehmen nach Umsatz (Mio DM) (6) | (1) Bewilligte Vorhaben | | (2) Bewilligte Zuwendungen | |
|---|---|---|---|---|
| | (3) Anzahl | (4) Anteil in % | (5) Mio DM | (4) Anteil in % |
| (7) bis < 20 | 331 | 68 | 74,6 | 62 |
| 20 bis (7) < 50 | 49 | 10 | 12,2 | 10 |
| 50 bis (7) < 100 | 48 | 10 | 14,7 | 12 |
| 100 bis (7) < 200 | 30 | 6 | 9,0 | 7 |
| 200 bis (7) < 500 | 24 | 5 | 8,4 | 7 |
| 500 bis (7) 1000 | 3 | 1 | 1,3 | 1 |
| Insgesamt (8) | 485 | 100 | 120,2 | 100 |
| darunter NBL (9) | 9 | 6 | 2,5 | 8 |

Stand: 31.12.1993 (10)

**Table 2.2: Indirect-specific support: 1990-1993 MST support focus**

Key: 1. Approved projects; 2. Approved funding; 3. Number; 4. Share in; 5. Millions of DM; 6. Firms on the basis of turnover (millions of DM); 7. Up to; 8. Total; 9. Including NBL; 10. Cutoff date: 31 December 1993

maximum [max.] subsidy of DM400 thousand. Those targets were opted for by one fourth of the firms. Reflected therein is the current development status of MST on the product side: most prevalent are individual components that represent a preliminary stage for future integration in microsystems.

### Spread of Complex Technologies Just Beginning

To a great extent relatively "mature" technologies like SMT and thick film were used, while the complex technologies still have their broad industrial application in the future. For nearly half of the firms the supported project was the occasion for embarking on one or more MTs, while under the supported project the others plumbed their experiences with a technology already familiar to the firm to develop new product solutions.

Contrary to much skepticism, many small firms are capable of managing sophisticated projects involving a number of MTs; this is evident in a number of supported projects as well as in industry as a whole. However, on the statistical average, the level of technology between large and small firms is (still) clearly diverse: meaning that two percent of companies with less than DM100 million in annual turnover possess thin-film technology, integrated optics or micromechanics while this is the case for 12 percent of firms having more than DM100 million in annual turnover.

As a rather recent empirical survey demonstrates[8], the average outlay per innovative project by MST firms supported with close to DM1.2 million was approximately three times as high as that by unsupported firms.

### Innovative Management As a Success Factor

If new technologies that have not yet been applied hitherto are introduced in a firm, this has to be accompanied by new strategies in innovative management. Among other things, these include careful prior clarification of market prospects as well as adaptation both of the operational organization and the qualification of the employees to the requirements resulting from the increasing complexity. This has been substantiated by field studies[9] in which MST firms were compared with others. Nearly two thirds of the firms worked on those problems in the context of preliminary phases while concomitantly with the actual R&D activities, qualification and organization were worked on in a fourth of the projects.

Cooperation with third parties is of particular importance in MST prototype development: more than three fourths of the projects provided for cooperation with third parties—especially with research institutes and other firms. Frequently, there was simultaneous cooperation with three or more outside partners. The firms in the support projects thereby benefited from the opportunity to expand and intensify their network of contacts.

So far no close forms designed for the long term, like joint ventures, have been opted for.

In general, however, cooperation with third parties in R&D represents a more costly and even riskier approach, above all, for smaller firms: there are sometimes problems to be resolved that may determine the cost/benefit ratio of cooperation from the search for an appropriate partner through contractual designing of the cooperation to trustworthy conveyance of the required company know-how and utilization of the results.

**Supported Firms Having Exemplary Innovative Management**

Firms that have picked up on the special offer available in support react differently to the complexity of technology and the increasing tempo of product innovation from firms that have made no use of it[10].

Supported firms:

- have advanced technological equipment,
- display higher R&D intensity,
- have more highly qualified personnel,
- merge organizational and technological development,
- have a denser network of contacts and more pronounced outreach orientation,
- are more powerfully market-oriented even starting with the product concept,
- have a stronger presence on the international markets.

Such features point to successful strategies for introducing MST whereby faster innovation cycles with increasing demands for innovation can be coped with. It is becoming apparent that formation of innovative management goes "hand in hand" with an increased level of complexity in the technological projects.

### 2.2.4 Information and Arranging of Contacts

Rapid orientation in a complex and dynamic field is required successfully to exploit the opportunities of MST. The data needed as a basis for decision-making can be acquired only at high cost by individual firms. The technology transfer projects facilitate access to information here and this is advantageous to SMEs, above all, in view of their scantier resources. Over and above arranging for information, a more active process of communication and coordination on the part of the players from research, industry, chambers, associations and government is being encouraged.

**Informaton Creates Transparency**

Additionally, a number of projects whose results contribute to transparency and surer decision-making by the players was supported under the MST support focus. What is more, as a result of the broad and timely availability of the technology transfer projects' results, simultaneously the concept of MST and microsystem solutions was also made known and accessible to a larger group of users—especially even the SMEs.

MST encompasses a large number of technological fields that are variously ripe for industrial applications both individually and in their possible combinations. Surveys were formulated for 12 technological fields that are tailored for SMEs' demand for information: the current status as well as the effectiveness and future potential of each technology can be derived only at some expense from many different specialized data and from expensive studies that are available to only a handful of financially well-off industrial firms.

Neutral, survey-type presentations have been prepared and made accessible to SME decision makers. An MST study was also elaborated dealing with firms and services in the new laender. Altogether, more than 1,800 copies of those surveys were sold—mostly to industry. Data on MST's technological and applied potential have been routinely published, especially in specialized publications. Section 5.3 lists publications on the subject of MST.

**Conventions as MST Forums**

To the extent required, conventions and fairs were supported that were eager to take up the subject of MST but still were unable to anticipate sufficient revenue for it: the ACTUATOR deals with the rapidly developing technologies for piezoelectric, magnetostrictive and chemical actuators, above all, for the motor vehicle supplier, machine building, automated technology sectors as well as manipulator technology and the electrical industry. At a special exhibit of the SENSOR specialty fair, more than 100 research and university institutes as well as industrial firms had a chance to display their extensive menu of services. Represented at it for the first time in 1991 were 25 institutes and firms from the new laender. Supported by the Berlin senate, MICRO SYSTEM TECHNOLOGIES gave rise to a number of events having MST as their central theme.

**Partner Wanted for Cooperation**

The "right" partners are not always easy to find in the new and rapidly developing field of MST players. In this context, the "MST: Who is Who?" database affords access by technological content, region, activity and type of institution on ca. 6,000 suppliers, cooperative partners, etc., from research and industry. The heavy demand for this service demonstrates the great need for orientation in the MST "scenario."

Since the MST theme cannot remain limited to a national field of action, the VDI/VDE-IT, under the "International Relations in MST" project, offers, among other things:

- advice on EU Commission research and technology programs that are thematically related to the MST sector

- advice on possibilities for cooperation in Europe in the MST sector
- symposiums and workshops on Europe's opportunities in MST
- data on international conventions, seminars and fairs
- an international newsletter "MST NEWS."

### Technological Service Suppliers Are Getting Established

Gaps in information and advice offered on MST technologies were determined following a preliminary stocktaking in mid-1990. On the basis of that and still in 1990, funding was provided for a total of 12 service centers at research institutes. The subsidies will be completely done away with in a few years; at which time the centers will have to hold their own on the service market. In the field of the MST R&D market, subsequently, further surveys noted a high mobilization for MST thematic sectors. It turned out in the studies[11] that in the technologically "more mature" fields of MST the exploitation of know-how and systems was offered on market terms already even apart from the support of universities, research institutes and firms, while in other thematic fields of MST, even though there is a demand for such realizations it still could not be covered on the market.

There is, for the most part, still no service offer for producing small series of microsystems or their components in the non-industrial sector. The problem of product liability keeps R&D institutes from closing those gaps to a larger extent.

For SMEs especially, employee qualification is frequently a pinch point in product and process innovation. That is why the VDI/VDE-IT made advice on personnel and organizational development available. The continuing education, information and research [WIR] database for continuing education is being used for this purpose. With more than 600 suppliers it is the largest such database in the new technologies sector.

### Technology Designed for People

For selected areas of MST an attempt was made to explore the latitude for design in the application of MST. For example, dialogues were initiated between producers and consumers—e.g., in medical technology and environmental technology—among whom the basic conditions for the exploitation of the new options for MST were discussed. Proposals for industrial combined projects were also formulated in such discussions (e.g., for the project "MST Components for Minimally Invasive Operating Technology").

### MST Influences Job Quality

Industrial automation technology is the applied field for which numerous MST solutions have already been developed. Therefore a number of impetuses for job content and design may be anticipated from MST. For example, automation technology products that base their competitiveness on the use of microsystems create and safeguard jobs. What is more, the use of advanced automation technology in production makes productivity increases possible. During the marginal economic conditions of the eighties the employment of new technologies resulted in a positive impact on the job market in terms of the total economy. At present, the use of appropriate automated technologies appears to be crucial for the preservation of entire branches. But microsystems also result in design options for the qualitative dimensions of the job world. The substance and caliber of the work of engineers and specialized workers may change with the development and production of microsystems, e.g., through the use of new tools for simulation. Even the human/machine interface can be further developed through the possibilities of MST. New sensor-actuator combinations also are opening up additional possibilities for job security.

In summary, it can be stated that the demand for information cannot be covered by in-house endeavor given the rapidly changing technological potentials of many firms and multipliers. Many SMEs that are searching for access to MST still continue to feel that the transfer landscape is not transparent enough.

## 2.2.5 Opportunities for R&D Institutes and Firms in the New Laender

German unification posed the problem, as early as the phase of radical change and restructuring, of timely integration of the firms and research institutes of the NBL in total MST development. That called for flexible and unconventional support appropriate to the problem.

Prior to the currency union, scientists from the German Democratic Republic [GDR] had only limited resources for travel and cultivation of contacts. Resources were made available here to overcome the initial hurdles.

In 1990 projects were formulated still in the DM budget of the Ministry for Research and Technology (MFT) that held the prospect of later integration in the specialized program structures of the BMFT. In that context also themes and technologies were involved that reflected the BMFT's microperipherals support focus (1985-1989) whose "connectability," however, with the growing areas of MST in the original laender was a given. Those projects had a support volume of DM15.5 million. In 1991, MFT support was continued by the BMFT and, in fact, at a total volume of DM30.7 million. As a rule, researchers and firms having those projects quickly found their connection with current combined MST support.

Moreover, to strengthen the relations on the working level between institutes and teams in the original and the new laender and to accelerate the joint growth of both parts of Germany in the field of MST, supplements were provided for the general support quotas for private sector firms and universities in the NBL.

In the meantime, through timely and active integration, the participation of NBL partners in the combined projects has been a success: NBL partners are participating in 70 percent of all MST-combined projects approved since 1991 and they have gotten more than 20 percent (DM48.4 million) of the federal funds approved for combined support since 1991. But the NBL partners did have to struggle with the problem of only a few suitable partners being available for R&D tasking for the researchers in their related field because of the meager and at the time still dwindling industrial base in the NBL.

Since the service centers that had been set up still in 1990 were all located in the original laender, additional partnerships were supported among 13 research institutes in the East and the West to consolidate the potential in a few thematic fields that had still not been considered for the offered services.

## 2.3 Other Federal Support Activities Involving MST

### 2.3.1 Support Organizations and Research Institutes

In the context of German Research Society support as well as in the working programs of the Max Planck Society and the other institutionally supported research institutes themes relative to MST have already now been dealt with, most of them classifiable as basic research. Actually, a program like MST having a strong applied orientation would be inconceivable apart from such a basis created jointly with the universities. Insofar, however, as industrially relevant R&D is addressed in the respective work programs, the existing program should contribute towards coordination commencing where mechanisms for coordination among the respective players in the system for innovation still have not been fully developed.

Outside of the universities, institutes with federal institutional support muster the greatest scientific potential for MST supported with public funding in Germany. Hence, listed below are the research institutes in whose financing federal government participates, together with their activities in the context of the MST program.

**Karlsruhe Nuclear Research Center GmbH [KfK]; Karlsruhe**

Project management of the MST project (PMT-PL)

—Coordination of KfK in-house and external MST activities; spokesperson partner for cross-institutional cooperation with other research institutes and industry

Institute for Microstructure Technology (IMT)

—LIGA process based microstructuring (x-ray lithography, electroplating and molding, including full masking technology); mechanical microstructuring (machining with tools formed by grinding); structuring with light and particle beams (electron beam stylus, inert and reactive ion beams); advanced structural and linkage technology for the development of complete microsystems

Institute for Applied Computerization (IAI)

—Computer-aided methods and tools for designing, modeling and simulating microsystems; information-technology integration of the LIGA process including quality assurance; computer-aided management technologies for microassembly and medical technology

Institute for Radio Chemistry (IRCh)

—Chemical microsensor systems based on various transducer principles (optrodes, MOF and SAW [Surface Acoustic Wave] sensors, ChemFET [Chemical Field Effect Transistor]); thin-film production

Institute for Materials Research (IMF)

—Development and characterization of new materials ("smart materials," ceramics for use in the LIGA process); process technology for microsystem compatible processing of new materials; CAD/FEM [computer-aided design/finite element method] methods for the analysis of microstructures; thin film and surface technology

Central Division Engineering Technology (HIT)

—Development of instruments and systems for medical technology, especially minimally invasive surgery

**Juelich Research Center GmbH (KFA); Juelich**

Fiber optic sensors development group

—Fiber optic sensors, film technologies, microstructuring, semiconductor sensors

**Society for Mathematics and Data Processing Limited [mbH] (GMD); Birlinghoven**

Institute for systems design technology

—Design process for integrated mechanical-electrical microsystems; efficient simulation process for complete systems

**Fraunhofer Society for Support of Applied Research, registered [e.V.] (FhG); Munich**

Fraunhofer Institute for Silicon Technology (ISiT); presently in Berlin, later in Itzehoe

—Silicon technology component development; MSTs, structural and linkage technology, systems integration, standardization, quality assurance, process and component simulation

Fraunhofer Institute for Solid-state Technology (IFT); Munich

—Integrated microsystems; sensors, actuators and microfluid systems; semiconductor, micro-, film technologies, hybrid microelectronics; structural and linkage technologies; production equipment for special MST processes; systems integration, process and component simulation; design tools for microsystems; training

Fraunhofer Institute for Physical Measurement Technology (IPM); Freiburg

—Fiber and integrated optical sensors, thin-film sensors; technologies for sensor production, training

Fraunhofer Institute for Microelectronic Circuits and Systems (IMS); Duisburg, Dresden

—Sensors and actuators in silicon-semiconductor technology, microsystems involving integrated sensors and actuators, systems integration, process and component simulation, film technologies, training

Fraunhofer Institute for Reliability and Microintegration (FhE-IZM); Berlin

—Simulation of thermo-mechanical properties; optical and x-ray measurement technology for microsystems; MCM [Multi-Chip Modules] design technologies, chip bonding technologies, metallic-bonding systems, soldering and SMD [Surface Mounted Devices] technology

Fraunhofer Institute for Production Technology and Automation (IPA); Stuttgart

—Microsystems production strategies

Fraunhofer Institute for Biomedical Technology (IBMT); St. Ingbert

—Sensors, actuators, microsystems for medical applications, thin-film, thick-film technology, structural and linkage technology, simulation, training

Fraunhofer Institute for Applied Optics and Precision Mechanics (IOF); Jena

—Thin films for optical and microelectronic components and sensors; analytics, process and component simulation; drives, storage devices, leads for mechanical-optical leads in μ ranges, training

Fraunhofer Institute for Integrated Circuits (IIS); Erlangen

—Application-specific integrated circuits, systems technology, signal processing, design tools for integrated circuits and microsystems, training

Fraunhofer Institute for materials mechanics (IWM); Freiburg

—Surface analytics, thin-film sensors, actuators, materials for MST (diamond)

Fraunhofer Institute for Information and Data Processing, Data Processing Sector (IITB-DV); Karlsruhe

—Signal processing for design of automated structures with microelectronic components, development of CASE tools

Fraunhofer Institute for Silicon Research (ISC); Wuerzburg

—Development and characterization of non-metallic, inorganic materials, materials for MST, structural and linkage technology, analytics, photo-structuring

**Max Planck Society for Support of the Sciences e.V. (MPG); Munich**

Max Planck Institute for Metals Research, Institute for Materials Science; Stuttgart

—Development, properties and reactive behavior of materials; crystalline metals and alloys, metallic smelting and amorphous alloys, ceramic materials and composite materials

Max Planck Institute for Physics (Werner Heisenberg Institute); Munich

—MST materials, especially scaling of mechanical properties at small dimensions, strength measurements

Max Planck Institute for Biophysical Chemistry (Karl Friedrich Bonhoeffer Institute); Goettingen

—Spectroscopy, laser physics, molecular biology, molecularly organized systems, neurobiology, membrane biophysics

Max Planck Institute for Computerization; Saarbruecken

—Sequential algorithms, especially data structures; networking algorithms

**Hahn Meitner Institute Berlin GmbH (HMI); Berlin**

—Electronic Measurement Technology Division (DM)

—Development of process for generation of simulation models for MST components

**Bundesmittel für institutionelle Förderung mit Bezug zur Mikrosystemtechnik im Jahr 1993 in Mio DM**

| KfK | GMD | KFA | FhG | MPG | HMI |
|---|---|---|---|---|---|
| 54,0 | 1,2 | 0,8 | 18,5 | 0,5 | 0,4 |

(1) Hierbei handelt es sich ausschließlich um Bundesmittel im Rahmen der Grundfinanzierung, hinzu kommt der Länderanteil in Höhe von 10 % (resp. 50 % bei MPG); die Institutionen werben z.T. in erheblichem Umfang Drittmittel zusätzlich ein.

**Table 2.3: Federal funding for institutional support for MST in 1993, in millions of DM**

Key: 1. This addresses only federal funding in the context of basic financing plus the laenders' share totaling 10 percent (50 percent respectively [resp.] for MPG); some institutions also sometimes attract a sizable volume of third-party funding

### 2.3.2 Federal Support Program

MST has a plethora of interfaces with other support programs. It builds on programs that support technological development by appropriately combining into systems currently existing results from programs in MST. To the extent that demands for systems capability are known in advance on the basis of an improved understanding of effective systems architecture and practicable design tools, precise requests can be transferred to other programs too. It is imperative for support programs that start with the solution of problems in the sector of concern to be integrated if the issue is defining microsystem solutions appropriate to the problem and later testing them in actuality.

This entails the following programs specifically:

A separate program is dedicated to continued technological development of microelectronics to the point of new effective principles for a nanoelectronics and application of microelectronics in innovative systems. Activities are carried out in the following foci: production equipment and materials for semiconductor technology, integration technologies such as multi-chip modules for increasing the complexity of microelectronic systems, CAD circuit board design and simulation, accelerated application of new potentials for microelectronics in innovative systems. In this context the desired applied systems increasingly determined the technologies of the microelectronics that will have to be utilized. A principal project, "Electronic Eye," was initiated for one special field of application. (BMFT department 415, project sponsor: DLR [German Research Institute for Aerospace], Berlin-Adlershof).

Basic technologies for information technology were supported as an additional field. It includes, e.g., II-V electronics for the production of high frequency and photonic components. The exploration of semiconductors having large bandwidth continues to be supported for the production of blue-emitting components or those suitable for high temperatures. The R&D results will influence MST. (BMFT department 412, project sponsor: DLR, Cologne/Berlin-Adlershof).

In the computerization program the continued development of teachable systems for the signals processing sector or the basis of neural computers and artificial intelligence (AI) is supported. Neural computers and AI have presently attained a technological status that will yield an extensive field of application for MST. Support of molecular biocomputerization is important for the development of functional biocomponents in MST. (BMFT department 413, project sponsor: DLR, Berlin-Adlershof).

MST has links with the "Work and Technology" program. It creates new possibilities for technologically supporting process control. Miniaturized sensors in machine tools, industrial robots and production equipment increase process transparency for the user and thereby contribute toward process control. Sensor-actuator combinations support humans in the implementation, monitoring and direct influencing of processes. It also opens up fresh possibilities for job protection and quality assurance. (BMFT department 421, project sponsor: DLR, Bonn).

R&D activities that address not only improved materials properties but also the structural design and mechanical

and chemical protection of microcomponents, are supported in the "Materials Research" program. A basic requirement for the realization of new products and processes in MST is the availability of well-defined materials and technologies for processing them. Ceramic, metallic and polymer functional materials, above all, are in the forefront of interest for signal processing. (BMFT department 422, project sponsor: KFA, Juelich).

Problems entailing production, alteration and characterization of functional surfaces and films are addressed in the support program "Surface and Film Technologies." (BMFT department 423, project sponsor: VDI/VDE-Technology Center [TZ], Duesseldorf).

Uppermost in laser research and laser technology are basic activities for new generations of lasers and the development of fields of application. The general goal is total control of coherent light in all its properties with miniaturization and more compact design of laser beam sources characterizing the emerging scientific and technological lines of development. That applies, e.g., to projects such as high-performance diode lasers and diode-pumped solid-state lasers. In the field of laser applications too, the development of laser components is supported that, synergistically with MST, will constitute a major potential for new developments, e.g., in the field of medical technology (minimally invasive therapies), measurement technology and modern analytics. (BMFT department 426, project sponsor: VDI/VDE-TZ, Duesseldorf).

Two main directions are emerging for biosensors in the biotechnology program. One is characterized by the integration of biological sensor components in MST. The other direction is characterized by biological components aimed at new biomolecular functional systems for technology with special applications for synthesizing of materials, processing of information or energetics. (BMFT department 325, project sponsor: KFA, Juelich).

The "Health Research 2000" program uses individual examples as models and provides an assessment of preventive, diagnostic and therapeutic processes from clinical and health-economics perspectives. (BMFT department 322, project sponsor: DLR, Bonn).

The development of environmental technologies to avoid and eliminate environmental pollution requires reliable measurement and analysis technologies, the basis for which could be future MST components. Moreover, MST is suited to the development of measurement, command and control installations for low-emission operation of many technological processes. (BMFT department 523, project sponsor: DLR, Bonn).

Wrapping up, programs for innovation support may also be mentioned wherein, among others, the application of MT or MST too is supported.

The program "R&D Lending for Small Firms for the Application of New Technologies" should open up for small firms the possibility of applying technologies for product innovation that until then were still not relevant for that firm. Nearly half of the currently supported projects involve MT.

The model experiment "Share Capital for Fledgling Technology Companies," improves the corporate capital status of fledgling technology firms, even through the inclusion of silent shares or refinancing of shares. Nearly 45 percent of fledgling firms use MT functionally. (BMFT department 414, applications for co-investment: tbg, Bonn; for refinancing: Credit Bank for Redevelopment [KfW], Frankfurt).

Fledgling companies in the new laender are supported with R&D subsidies and with loans for market penetration. Altogether, 40 percent are developing MTs on their own or using them functionally in their projects. (BMFT department 126, project sponsor: VDI/VDE-IT, Teltow).

Under support for commissioned research in the new laender, externally awarded R&D activities are supported. A high percentage of MT themes is also involved here. (BMFT department 126, project sponsor: AIF [Association of Industrial Research Organizations], Berlin).

### 2.4 What Support Measures for MST Are There on the Laender Level in the FRG?

In addition to federal support for MST, and here especially by the BMFT, some of the laender have designed support programs involving MST thematic complexes.

Baden-Wuerttemberg has embarked on sizable initiatives for restructuring the Karlsruhe KfK (cf. section 3.2). An "MST" focus has been developed at the university of Karlsruhe in association with the KfK. The Hahn Schickard Institute in Villingen-Schwenningen for MST was also established. In close cooperation with the universities in Karlsruhe and Furtwangen, a center was set up to offer services in the R&D sector. Also, at the university of Freiburg a technology department with seven chairs having an MST focus is being installed.

The Bavarian Free State is planning to design a support program for MST bundling the various activities in the research field. The founding of a Bavarian MST research combine is planned. It will be an amalgamation of university chairs, scientific institutes and private sector firms aimed at jointly fostering applied R&D in the field of MST. The Bavarian government is also considering support for improving the land's research infrastructure in that field.

The land of Berlin, with its contribution to the focus "Microperipherals Technologies," has laid the basic groundwork at the Berlin TU for implementation of the technological aspects of MST. In 1993, the IZM was founded with its primary focus on MST. It cooperates closely with Berlin TU on the basis of a cooperative

agreement (cf. section 2.3.1). The Berlin senate also supports the MICRO SYSTEM TECHNOLOGIES event.

In Brandenburg, at Cottbus TU, MST is being moderately developed.

MTs are included in the foci for development of the R&D infrastructure of the Free Hansa City of Bremen. Under an MST research focus at the university, an institute for microsensors, -actuators and -systems has been set up.

The Free and Hansa City of Hamburg is supporting the expansion of the center for microstructural research that will enhance the basically oriented research of the two land universities.

The Institute for Microstructural Technology and Optoelectronics (IMO) in Wetzlar is an MST R&D center created by mid-size industry in Hesse. The institute is sponsored by an association of more than 40 member firms from Hesse and, in cooperation with Kassel university, affords interested firms the possibility of elaborating scientific know-how and turning it into marketable products and processes.

In Mecklenburg-Vorpommern, in the context of the reprofiling of the university, consideration is given to the needed capacities for forward-looking MST research. The land's own technology support program focuses on MST.

In Lower Saxony, the SICAN [Society for Silicon Applications] group is engaged in the MST sector as a state and federally supported institute. It coordinates the various MST activities among Lower Saxony, Hamburg and Thuringia. Through re-establishment and reorientation of institutes, the TU of Braunschweig and the university of Hamburg have made sizable investments aimed at MST. Together with non-academic institutes, a sizable potential has been developed for extensive, interdisciplinary processing of MST tasks.

In North Rhineland-Westphalia, an MST initiative is under development. In a number of the land's colleges MST is also being anchored in the curricula. An example of the spread of MST is afforded by the Institute for Chemo- and Bio-Sensors (ICB) in Muenster that was founded in 1991 with the possibility of implementing the development potential of MST for sensors and analytical technology. Targeted research, R&D activities verging on practical application as well as offerings for advanced training and transfer of know-how in the fields of chemo- and biosensors are being conducted here by an interdisciplinary team of scientists and engineers from the areas of chemistry, biology and engineering.

In late 1990, the Rhineland-Palatinate land, with the Institute for Microtechnology at Mainz (IMM), created a land center for MST. In three years' time a research institute equipped with highly modern technology was the result, having at its disposal general process lines for LIGA technology, for silicon micromechanics, thin-film and plasma technology. Jointly with industrial firms and research institutes, IMM develops microstructural products as well as the appropriate materials and production equipment. In cooperation with universities and colleges, scientists and engineers get MT training that verges on practical application. The Institute for Surface and Film Analytics (IFOS) at the university of Kaiserslautern also is engaged in application-oriented activity in the MST sector. The IFOS has a modern, comprehensive inventory of equipment available for the development and application of modern processes for the chemical and structural analysis of surfaces, thin films and solids as well as for service analyses.

In 1989, in the Saarland, on the initiative of the region's industry, a society for MST support was founded. Under the theme "From Material to System," the Institute for New Materials, the Fraunhofer Institute for Biomedical Technology, the university, the Saarland College for Technology and Economy as well as regional firms work closely together on the "MST" research focus.

In Dresden there is the "Saxon MST Support Association e.V." that is engaged in research and precompetitive development and all associated MST activities in the Free State of Saxony for the purpose of support for science. In the structure of the TU of Dresden there is the Institute for Semiconductor and Microsystem Technology with the MST chair. At the TU of Chemnitz-Zwickau the Center for MTs was established. In addition to Duisburg, the Fraunhofer Institute for Microelectronic Circuits and Systems has one leg anchored in Dresden.

In Saxony-Anhalt, research in the field of MST is presently concentrated at the TU of Magdeburg and the LVA [Land Testing Institute] of Halle.

Schleswig-Holstein is planning a land-wide MST technology combine in which all pertinent institutions, firms and institutes are participating. With the assistance of the technology foundation and the technology transfer center of Schleswig-Holstein, the colleges of Luebeck and Kiel, the engineering department of the university of Kiel, the ISiT that is under development in Itzehoe as well as other research institutes will propose a coordinated concept covering the entire MST sector, basic and applied. The foci will be structural and linkage technology, microsensors and -actuators, design and production of hybrid circuit boards as well as the development of new functional materials. Medical technology is at the core of the applications.

In 1993 in Thuringia a research initiative was established in the field of microoptics. The IOF, the Institute for Advanced Physical Technology e.V. (IPHT), the Friedrich Schiller university of Jena and the college of Jena are working jointly with partners from industry on

research projects in microoptics. MST is also represented by the TU of Ilmenau, the Institute for Molecular Biotechnology e.V. (IMB), Jena, and the Institute for Bioprocess and Analytical Measurement Technology e.V. (IBA), Heiligenstadt.

### 2.5 How Is MST Support Viewed in the EU Zone?

The development and exploitation of MST points across national borders to an active role by the EU Commission and their coordination of European activities. In comparison to efforts in Japan and the U.S. this entails

- an active trade policy that recognizes and prevents unfair practices,
- the formulation of behavioral patterns for international cooperation that integrates R&D institutes too in addition to the commercial interests of firms,
- international norming and standardization to afford producers and consumers assured behavior,
- the position of European partners in internationally strategic alliances for complex microsystems on mass markets,
- support for specific R&D themes such as top-down design or production technologies for microsystems that are better tackled on a European level,
- European-wide communication among firms and R&D institutes to realize a synergistic effect,
- improved qualification for MTs, systems technologies and innovative management to upgrade international flexibility and cooperation.

On the basis of the subsidiary principle, the EU is accountable only for responsibility involving "European added value" that cannot be managed on the level of the member states. Consideration of MST in the revision of the third and in the fourth R&D framework program therefore does not gainsay national programs in this sector especially if they are essential to prepare the national R&D structures for international cooperation and to implement international R&D results in the national structures. The future of European development will also decisively depend on the extent to which SMEs are able to implement the respective status of cutting-edge technological development.

Numerous projects of the EU Commission's third R&D framework program contain elements relevant to MST (among others, in ESPRIT [European Strategic Program for R&D in Information Technology, RACE [R&D in Advanced Communications Technologies in Europe, DRIVE, BRITE/Euram [Basic Research in Industrial Technologies for Europe/European Research for Advanced Materials, BCR, TELEMAN, JOULE [Joint Opportunities for Unconventional or Long Term Energy Supply], MAST [Maritime Sciences and Technology], SCIENCE, MONITOR, VALUE). In the second invitation to tender for the 1993-1994 ESPRIT III program, having a total volume of 400 million European Currency Units [ECU], MST already plays a central role. It is represented in the areas of "microelectronics," "CIME" ["Computer Integrated Manufacturing and Engineering"], and "basic research" with specific research responsibilities. A "Network of Excellence in Multifunctional Microsystems" (NEXUS) is already supported that has as its task the intensification of the European-wide information process for MST among the institutes mindful of Industry's interests. A bundling and consolidation of MST support are provided for the fourth framework program (1994-1998). The planned specific program for information technologies has a concentration of support in multidisciplinary design, integration and test methods as well as production processes. As a result, MST is considered in its interdisciplinariness and complexity even on the EU level.

In 1993 in France an invitation to tender for the submission of research applications in MST was published as a joint initiative by three ministries as well as the "Agence Nationale de Valorisation de la Recherche" (ANVAR).

Significant research activities have been carried out in the Netherlands. The university of Twente has founded a new Institute for the Development of Microelectronics, Materials Development and Sensors and Actuators (MESA). The research activities of that institute are closely linked to industry.

In the United Kingdom, a Microengineering Common Interest Group was set up with the support of the British Ministry of Industry (DTI) in which more than 100 firms, research institutes and universities are already represented. It has as its aim the spread of data regarding technological and economic developments in MST, providing orientation for the production of MST products and preparing support programs.

In Italy too there are ongoing activities in the MST sector that are under the control of industry for the time being. But in universities, e.g., in Pisa, the theme is also being broached.

### 2.6 Other Support Activities Outside the Country and International Trends

#### 2.6.1 Support Activities in Japan

In Japan, MST was broached in its very different facets and will be intensely worked on in the future. Intensive cooperation by large firms in selected fields with public authorities assuming a major role as moderators is typical. Published budgets for support activities frequently only reflect the percentage of funding expended for moderation of the joint orientation. Following is a sampling of activities in Japan.

In 1991, MITI [Ministry of International Trade and Industry] designed the "Micromachine Technology" project and in 1992, in connection with it, participated in the founding of the Micro Machine Center (MMC) in Tokyo. Also involved in that center are 24 industrial

outfits—including Japan's largest—plus the Agency of Industrial Science and Technology and the New Energy and Industrial Technology Development Organisation (NEDO). Basic research, components and systems development will be engaged in over a ten-year period with coordinated strategic planning. Problems of standardization and training are integrated in it. Between 1991-2000, MITI alone is laying out a total of 25 billion yen (ca. DM380 million) for that partial aspect of MST.

Support of R&D in the field of sensors is highly complex since many private firms and a large number of public and semi-public institutions are involved. Besides MITI, participants include the National Aviation & Space Development Agency (NASDA), major trade organizations, the Japan Electronic Industry Development Association (JEIDA), and intermediate Organization for Japan's Electronics Industry and the Research Development Corporation of Japan (JRDC). As reported by the Japanese Technology Evaluation Center (JTEC), headquartered in Maryland, U.S.A., since 1985, more patents for biosensors have been applied for in Japan than in the U.S. and Japan combined. This clearly indicates that in Japan considerable attention is lavished on the subfield of biosensors. This incomplete listing of support activities in MST subsectors shows that in Japan many millions of DM are being allocated annually on R&D by government and industry.

### 2.6.2 Support Activities in the U.S.

Major MST endeavors are also being undertaken in the U.S. Development there goes under the rubrics of "micromechanics" and "microrobotics" as well as "micro electro mechanical systems" (MEMS). R&D support is spread over various programs.

The Engineering Research Centres Programm (ERC) plays a central part. The goal it pursues is first, to combine basic research and the engineering-sciences disciplines to thereby support applied research and, second, to train students and scientists in interdisciplinary activities. Currently, the ERC is supporting 18 centers in six technological areas: design and production, materials research, optoelectronics, microelectronics, telecommunications, biotechnologies, energy research and infrastructure. The centers receive basic support; additionally, industry participates with assistance for the total center, laboratories or individual projects.

Considerable research capabilities have by now been developed at the University of California, Berkeley, the Massachusetts Institute of Technology (MIT), the University of Wisconsin, Harvard University, North Carolina State University, Carnegie Mellon University and other public and private research institutes. Besides cooperative activities, the private sector shares directly in developments and results.

On the state level, MST development is supported by the Chamber of Commerce and the National Institute of Standards and Technology (NIST). NIST also oversees the Advanced Technology Program (ATP) whose assistance especially supports leading-edge technological projects in SMEs. The entire program for 1993-1997 has a volume of $1.4 billion.

In the Clinton administration's new technology policy focus, MST plays a major role in the conversion of defense technologies into civilian industrial projects. A plethora of projects is being coordinated by the Advanced Research Projects Agency (ARPA). ARPA annually allocates ca. $300 million for the development of production technologies.

But other established research institutions too, such as NASA or the Federal Coordinating Council for Science, Engineering and Technology (FCCSET), are being intensively oriented towards industrial MST projects. One subsector of the National Technology Initiatives supported there that also entails major MST developments is "advanced materials" (1993, $1.82 billion) and for 1994, "manufacturing initiative."

Support of micromechanics—one of MST's many technological fields—is being greatly increased. This field of research is being supported by various institutes like the National Science Foundation (NSF), the National Institutes of Health (NIH), NASA and the Depart of Energy (DOE). Total federal outlays just in that field of technology more than doubled in a single year: from ca. DM10 million in 1990 to ca. DM25 million in 1991. Since similar increases can be expected in subsequent years, it turns out that in the U.S. sizable support funding worth several million DM is available from the government for the various subaspects of MST. Total support of micromechanics activities by the government is not available. Most activities are carried out at the Sandia and Lawrence Livermore National Laboratories as well as in numerous university institutes having additional institutional support.

Considerable funding is available in the U.S. too for the transfer of technology from government research institutes to the private sector. In this way, generally, besides exceptional basic research capabilities, product-oriented R&D activities are also supported.

### 2.6.3 Support Activities in Other Countries

Besides the U.S., Japan and the EU countries, other nations too are investing in future MST technology. Besides national activities in Australia, the cooperation of Melbourne University of Technology, e.g., in a major project of Japan's MMC deserves mention.

In Switzerland, at the Institute for Microelectronics (CSEM), in Neuchatel, a considerable potential for sensor research and the development of micromechanical components has been developed as an expansion of traditional precision engineering for, e.g., timepieces. The research and instructional programs of the ETH

[Federal Technical Schools] of Lausanne and Zurich have included MST elements for a long time now.

Research institutes in Russia, the Baltic states, Belarus and Ukraine are increasingly engaging in MST. There are also the extensive experiences and the potential of the space and weapons research centers there that are focusing MST developments on marketable products in the framework of conversion.

There are reports out of China too regarding domestic MST developments.

### 2.6.4 International Market Prognoses

So far there are no sufficiently reliable, comprehensive, internationally comparative studies of the worldwide markets for MST available. Any assessment of future markets is freighted with corresponding uncertainties; among experts, however, the prevailing opinion is that fast growing market volumes can be anticipated in MST and will be determined by MST. There are assessments for individual product and applied areas that provide an impression of expected developments.

The lion's share of turnovers currently realized using MST components goes to systems capable microsensors. The international market for such components in 1990 amounted to ca. DM10 billion; Europe's share is projected at 20 percent. By the year 2000, the international market is likely to increase more than fourfold.

In the automotive sector, the MST share may amount to between two to four percent of production value. As a result, it is likely—on a conservative estimate—that in Europe the value of MST in total automotive production will be between four and six billion DM in the year 2000. MST will become increasingly relevant in the environmental sector too, and, e.g., the value of MST components for water treatment plants is likely to total ca. DM 600 million on the European market in the year 2000. Projected annual growth rate in this sector is 30 percent.

Considering that the European market constitutes only a fraction of the total market and it has not been possible to take into consideration new MST products still to be realized, it becomes evident that MST may develop a sizable market even on the international level.

## 3. 1994-1999 MST Program

### 3.1 Technology Policy Basis

Rapid technological progress is among the most significant competitive indicators of market economy economic systems. Numerous innovative firms—even in the area of MST—constantly search for improved technological solutions for new products and more efficient production processes to safeguard or expand their earnings possibilities.

Responsibility for the required R&D even in the MST sector primarily lies with the firms themselves that are able to assess and fulfill the demands, especially of consumers, on the basis of their market knowledge and experiences.

In the context of the indicated responsibilities of the private sector, the government is empowered to take the initiative only where critical R&D gaps are recognizable that disadvantage the nation's economy as a whole. Hence, government support is oriented on the principle of subsidiarity: only if companies themselves do not develop specific technologies of major importance for the economy as a whole or do so inadequately or not speedily enough does the federal government essentially see grounds for official R&D support in the private sector. It therefore limits itself—as much as possible—to assisting self-help.

Because of anticipated contributions to solutions for the structure of the economy, easing of environmental pollution and health, MST is included in the technology of the twenty-first century [12]. It thereby helps to safeguard the FRG's position.

The BMFT attaches special importance to MST since there are indications that

- MST might enable the realization of new functions that could be integrated in areas of governmental concern benefiting the public, such as medical care, protection of the environment or transportation infrastructure (cf. section 1.2.1).

- MST will have acquired a significant market for itself as, e.g., a system of microanalysis (cf. figure 1.7).

- As part of macrosystems, microsystems will decisively contribute to the competitiveness of the former (cf. sections 1.1 and 2.6.4) and thereby furnish improved technological solutions for new and improved products as, e.g., in the case of the airbag.

Firms' R&D and innovative efforts, however, still mostly fall short of their desired scale in the economy as a whole. The reasons for this are due not least to untried cooperative behavior by many firms. Absent intensive cooperation, however, in the technological field of MST frequently no progress is realizable. Moreover, MST requires sizable initial investments at high risk that overtaxes the solvency of most mid-size industry.

That is why the BMFT intends, as explained below,

- to use institution support to help safeguard a competitive research infrastructure,

- to use support to clarify pending scientific issues targeted by preliminary scientific projects,

- to use support of industrial combined projects to promote the development of technology whose importance transcends individual firms or branches with particular attention to SME projects,
- to use support for scientific exchanges to enhance the exploitation of international basic know-how for precompetitive R&D,
- to broadly support the industrial dissemination and TA of MST.

Those goals are to be striven for consistent with the requirement for subsidiarity.

Those requirements occur in the demand for research in basic industrial research if the private sector lacks adequate incentive for it from the viewpoint of the profitability of the private sector and simultaneously if the results will benefit major areas of the domestic economy as a whole.

The requirements are met in the case of applied R&D in areas of government concern such as medical care, protection of the environment or transportation infrastructure if the private sector lacks adequate incentive for it from the viewpoint of profitability and the government has an interest in the availability of such MSTs even if it is not a user of the results itself.

The requirements are also met, as a rule, if SMEs tackle sophisticated microtechnologies in combined projects and want to exploit them using applied R&D. The federal government emphasizes this requirement since disassociating such firms from technological progress because of financial constraints resulting in an alteration of the balanced structures in the economy as a whole should be avoided and such firms are crucial for the rapid spread of MST in Germany.

Since MST encompasses an entire field of technology including microtechnologies and systems technologies—for easier readability those are included in the following chapter four—and the primary focus is exploitation of the synergistic effects of microsystems and refraining from fostering individual microtechnologies without reference to subsequent application in fields where required, priorities and non-priorities have to be continuously reformulated with the consensus of consumers and producers of microsystems and developers of technology. In the process, linking mechanisms have to be realized among the phases of the innovation process so that the elaboration of technological know-how leads to the development of competitive products and does not end up in a cul-de-sac. The accelerated conversion of the results of basic research into marketable products is one of the BMFT's points of departure for enhancing the technological competitiveness of Germany's economy that is so critical for the future of Germany's position.

For the entire sector of information technology and microelectronics the fact is that observable industrial R&D capabilities have to be linked even better with the public research system[13]. That is why it is worthwhile investigating the linkage process and improving it wherever significant improvements appear feasible. The assessment and evaluation of the MST support focus (cf. section 2.2) have demonstrated that such linkage processes are underway for the entire field of MST with the plethora of individual technologies, but they still require support. So far, for example, the opportunities for enhanced cooperation among firms for the transfer of microsystems and microsystems components that have already been realized to other applied sectors or opportunities for risk sharing in precompetitive R&D aimed at complex microsystems remain insufficiently exploited. Compared with the earlier MST support focus, the problem of developing microsystems has grown technologically more complex. In fact, in view of the increasing activities outside the country since then it is not only a matter of technologically realizing specific functions but to do a better job of selecting the applicable technologies and their interlinkage in such a way that the systems to be developed can also be produced cost effectively.

It is evident from experiences with the previous MST support focus that there are excellent prospects also for meeting the above indicated goals in the program period with official measures.

The other necessary grounds for success are also satisfied for support, that is, adequate scientific potential in Germany (cf. section 2.3.1) and industry that is receptive to innovation (cf. section 2.2.3).

For MTs and systems technologies that can be made systems capable and manageable especially for SMEs, tested processes for combined support are available and even the organization of institutional support can profit from them. There are likewise initiatives to more efficiently design the diverse forms for the dissemination of technology.

As a survey[14] indicates, MST primarily involves Germany's mid-size industry. Approximately 70 percent of current firms that presently are using MTs have up to 100 employees. A further 23 percent come under the 100 to 1,000 employees size category. On the basis of those structures and the major importance thereby attaching to SMEs in the continued development of MST, special attention is lavished on R&D support in such firms. Firms currently using MST are potential future users of MST.

### 3.2 Institutional Support's Contributions to MST

Institutes having federal institutional support combine the greatest scientific potential for MST supported with public funding outside of the universities (cf. section 2.3.1). This significant capability contributes to the scientific basis for MST and has to be viewed in connection with project support also (cf. sections 3.4 and 3.5).

The BMFT contributes to the basic financing of such R&D institutes in diverse forms:

- large research institutes

- Fraunhofer Society

- Max Planck Society

- blue list R&D institutes.

In the previous program period the institutional research landscape in the area of MST was significantly expanded. Even institutes in the new laender have adopted the thematic spectrum of non-academic research and expanded it as well as supplemented it with important perspectives in the framework of the program. Institutions confronting a thematic reorientation have opted for MST as a possible new focus in so far as they had already worked in this or a related field earlier. The BMFT welcomed such enterprising decisions by the R&D institutes and correspondingly supported their possibilities as partners or in the role of their representatives in oversight groups. Simultaneously, however, it pointed out that the R&D institutes had to seize their opportunities in MST cooperatively with industry and in competition with other players in the R&D scenario. Only dialogue between research and industry can keep scientific overcapacity from surfacing in some areas of MST while in other areas of MST there are insufficient capacities for basic technological developments.

*There are currently a dozen institutes and facilities active at the Fraunhofer Society with a noteworthy percentage in the field of MST. The new ISiT estimates 70 percent of its work program as the MST percentage; the institute for reliability and microintegration was founded specifically for MST. Other institutes and facilities have shifted their work programs considerably in favor of MST. Altogether, in 1992, those Fraunhofer institutes and facilities expended more than DM53 million on MST.*

Not only is there direct competition among R&D institutes for orders from industry but even the early stages of the R&D process are involved in the competitive situation. The BMFT, therefore, makes its impact felt on institutes with federal institutional support that engage in R&D relevant to industry by having the individual stages of the net worth sequence all the way up to conversion into products, processes or services taken into consideration in the conception of the R&D programs. Whereas previously the starting point was an unbroken sequence in the innovation process (basic research, applied research, precompetitive development, product development), it is now known that the occurrence of innovation is marked by lots of feedback loops and cross-linkages. The process of turning know-how into products thereby becomes, in fact, more complex but simultaneously it facilitates accelerated conversion. Such feedback loops and cross-linkages, depending on the respective themes and objectives, require distinct forms of limited cooperation between R&D institutes and firms.

In the area of basic preliminary research, R&D institutes select the themes themselves; they will endeavor, however, to tackle the kinds of themes that lead to an expectation of useful results in a foreseeable future for industrial applications.

*In 1992, in the context of a substantive restructuring, the KfK created an MST R&D focus. Under the new KfK focus continued development and application of the LIGA technology received special emphasis. In 1993-1995, it will annually expend up to DM60 million on this. Consonant with the specific possibilities of a large research institute, the KfK will mostly use its extensive capabilities for basic preliminary research on MST. MST, however, can really only continue to be developed meaningfully through constant interaction with possible consumers; for that reason, by 1995, the KfK will integrate 10 percent of its R&D activities in the MST sector under industry orders and a further 20-30 percent under cooperative projects with industry.*

The synchrotron beam sources required for further development of the LIGA technology currently are available at ELSA [Electron Stretcher Accelerator] in Bonn and at BESSI I [Berlin Electron Storage Ring for Synchrotron Radiation] in Berlin. With the construction of BESSY II, expected to come on line in 1998, an additional source of synchrotron radiation will be available for MST too. In 1995 a decision will be made regarding a possible dedicated synchrotron radiation source needed in the future for LIGA technology.

In general, the existing program aims also at helping to improve the collaboration of R&D institutes that are institutionally supported with project supported institutes and industry.

### 3.3 Support of Industrial Combined Projects

Support of industrial combined projects under this program only occurs if it is the most efficient instrument for realizing the project's goal.

In industrial combined projects at least two firms and one R&D institute cooperate to a significant extent. The support of industrial combined projects exploits not merely the scientific potential of the R&D institutes but also mostly develops economically desirable networks among the industrial firms, absent which, individual industrial investments often make no sense and consequently lapse. This general effect in the exploitation of technological options occurs intensively in MST.

The use and further development of modern, occasionally highly sophisticated MST technologies increasingly require very specific know-how and high investments such that firms are less and less able to establish complete systems solutions in their own firms. Over the long

term only the existence of a widely branching network of suppliers of materials and equipment, of service providers and know-how platforms will be able to ensure successful exploitation of MST.

The support is based on the principles of project support as they are laid down by the BMFT in the General By-Provisions for Project Support (ANBestP-BMFT) on the basis of expenses and in the By-Provisions for Subsidies on a Cost Basis (NKFT-88).

For industrial combined projects the percentage is between 30 and 50 percent of total costs/total expenses, respectively, depending on the size of the percentage of applied R&D[15] and the percentage of industrial basic research as well as of standardization, quality assurance, technology marketing and similar cross-activities. For firms from the NBL and the Eastern sector of Berlin the support quota is increased by 10 percentage points. Likewise, firms that satisfy[16] the EU definition of "SME" get an extra 10 percentage points. For SMEs from the NBL, the cumulative supplement amounts to 15 percentage points.

The target for industrial combined projects is

- continued development of systems technologies with which individual technologies and components are linked (cf. section 4.1) in the development of microsystems or requirements for further development of MTs are derived,

- precompetitive development for microsystems or their components and—if still not available—their production technology exploiting a number of individual technologies (cf. sections 4.2 and 4.3). The components should be able to be used for manifold product developments with priority going to standardizable components and the preparation of standardization,

- development of prototypes as examples of advanced microsystems for applications in areas of governmental concern (e.g., medical care, environmental protection, transportation infrastructure) and—if still not available—development for their production technology.

The combined projects should lead to results that constitute the technological-scientific basis for successful developments of innovative products. The contributions of R&D institutes should be limited in terms of time and content so that the desired results of the combined project can be consequently be realized.

Timely observance of existing norms is decisive for opportune market penetration (time-to-market). Furthermore, standardization of the microsystem components is the basis for appropriate batch sizes in commercial production. Still, the issue is not just any quantity of usable technologies but instead, whether microsystems can be produced cost effectively. Because of the economic importance, these aspects have to be appropriately clarified in the combined applications. In addition to the technological and scientific result of the respective combined projects, the opportunity should be seized for standardization concomitant with development[17].

The development of prototypes of advanced microsystems that exclusively target public demand in Germany are not the target of support under this program.

### 3.4 Support for Scientific Bases

The experience of the previous MST support focus demonstrated that there are more and more fields of application for MST and visions of sophisticated microsystems/microsystems families, for which there is still a scarcity of basic knowledge. Only after such basic knowledge is available can a decision be made as to whether any effort in the area of industrial basic research is justified. It follows from this that no financial participation of an individual firm can yet be anticipated in this initial phase of any project[18].

The new program, therefore, should open up the possibility of preliminary scientific projects in the case of justifiable exceptions with the problems calling for solution being posed by the potential industrial consumers.

Pure basic research may be supported up to 100 percent. At the conclusion of the preliminary scientific project there is a workshop that may either result in the cessation of the project or may lead to a succession of industrial combined projects.

The BMFT welcomes the participation of large research institutes together with other R&D institutes in the elaboration of scientific bases. The appropriate applications for it are allocated to preliminary basic research under institutional support.

### 3.5 Support for Scientific Cooperation with Foreign Countries

With basic know-how being increasingly elaborated at many different locations around the world it is insufficient for scientists and engineers from R&D institutes occasionally to meet at international conventions and effect exchanges in the context of talks.

The process of benefiting from basic know-how for precompetitive R&D may be enhanced by scientists and engineers from Germany cooperating for several months at appropriate centers in R&D institutes and firms abroad.

The sojourn abroad is supported by means of a travel-expense allowance. Applications may be submitted to the German Academic Exchange Service (DAAD) in Bonn. Qualified applicants include employees of either sex from those R&D institutes and firms that (have received or) are receiving project support in the field of MST.

### 3.6 Support for the Industrial Dissemination and TA of MST

The 1990-1991 analysis of the industrial spread of MST[19] demonstrated that there is in fact already at this time a host of firms that are using simpler MTs, but SMEs actually are going to have problems exploiting the next more complicated stages of MST. The bottlenecks consist in[20]

- acquiring reliable data enabling decision inside the firm regarding which MT will be profitable under which conditions for which products,

- financing appropriate product developments in small firms.

This program can help supply data by degressively supporting specialized exhibits to the extent that they are not yet sponsored by participant fees and contributions from associations, by making articles available to newspapers that will reach the respective industrial consumers or by realizing technological surveys at regular intervals and selling them at prices appropriate for a preliminary orientation.

Support for dissemination also includes a thoroughgoing concern for qualification, organizational development and marketing of technology as well as for the opportunities and risks for the users of microsystems or machinery, equipment and processes that incorporate microsystems. Technological design, acceptance and market opportunities are mutually interlinked in an interactive process. Studies and workshops on this theme could be supported.

There currently exist a large number of specialized and variously oriented service centers for MST that are capable of satisfying the demand with varying quality. Both the currently supported institutes and commercial firms will succeed over the long term only if they manage to develop stable customer relations reflecting their efficiency. Success requires not only well-grounded technological know-how but also competence in the acquisition and methodology of imparting that know-how. To realize the necessary efficiency, appropriate exchanges of experience should be improved and supported.

There is a single qualification to the assessment that the demand for advice, advanced training, R&D or production of microsystems as a service is adequately covered at present: if the future production capacity for complex microsystems in mass markets is considered, the requirement will be for European, not to say even international, coordination between consumers and producers (cf. section 2.5).

Financing the independent development of a few complex microsystems in separate firms is facilitated by the existing support offered in the "R&D Loan Program for Small Firms for the Application of New Technologies." Firms with up to DM50 million in annual turnover (including allied firms) are thereby afforded the possibility of using such technologies for product innovation as were still not relevant for the firm until that time. Applications may be submitted until 31 December 1997 via any credit institute to the Credit Bank for Redevelopment (cf. section 5.2).

Realization of strategic corporate goals in MST occasionally requires the melding of various industrial partners. Awareness of the partners' potential as well as appropriate forms of locating partners can be improved through transparency and the establishment of contacts. Financing of the costs of cooperation can be alleviated through support of the separate costs of R&D applications as a component in the development of products, processes or services under the above indicated R&D loan program.

There is also the possibility under the measure for "Research Cooperation" of ensuring subsidies with graduated support quotas and maximum limits for risky R&D projects that are conducted in transnational or national cooperation between at least two firms on the basis of a cooperative agreement. Applications may be submitted until 30 June 1998 via the association of industrial research groups (cf. section 5.2).

The BMFT also has the following support measures whereby, among other things, the dissemination of MST technologies can also be supported:

- "Commissioned R&D—AFO" support measure for firms in the new laender for support of R&D commissions that SMEs award for the solution of in-house technological problems to outside contractors aimed at acquiring new or improved products or processes.

- "Commissioned R&D—AWO" for R&D institutes and firms in the new laender for support of R&D commissions that firms headquartered outside of the new laender and of East Berlin award to contractors in the new laender and in East Berlin.

Applications may be submitted via the association of the industrial research group until 31 December 1994 (see section 5.2).

Furthermore, the Federal Ministry for Economy (BMWi) has designed two support programs:

- With the "Support for Projects at Research Institutes Close to the Private Sector in the New Laender" program, R&D projects are supported in innovative firms that make contributions to the development of market-precursor industrial research and to structural change in the economy.

- The program "Support for Development of New Products and Processes (Innovation Support) in SMEs in the New Laender," provides assistance to firms in the manufacturing sector for the development of innovative products and processes having a definite technological orientation.

Applications may be submitted via the VDI/VDE-IT GmbH until 31 December 1995. For further information on this program is available at the BMWi, department II D 6.

## 4. MST Technological Thematic Fields

Depending on the respectively chosen approach to the theme, different arrangements of MST's technological thematic fields are conceivable but if all aspects such as materials, technologies, components, functional principles, etc., are taken into consideration, no universally coherent classification of MST that avoids redundancies is possible. In the following chapters the pertinent MST technologies are categorized and presented by systems technologies, MTs and other technologies.

For the 1994-1999 program period, systems technologies are foremost. They link together the separate technologies and components in the development of MSTs.

In the sections that follow the conceptual explanation of each technology, respectively, is given first. Next, the exploitable applied potential of the technologies for microsystems in specific fields of application even at present is noted. Thirdly comes the future potential and the R&D required for its realization. Other support programs are referred to (cf. section 2.3.2) in development goals that are not covered by project support under the 1994-1999 MST program.

### 4.1 Systems Technologies

Systems technologies support the linkage of the individual technologies and components in the development of a microsystem. They include both design tools that take systems integration and the environment for application into account and processes for the technological realization of such linkages.

Current MST developments have indicated that on the basis of R&D in the individual technologies, successes are predominantly realized in partial solutions like microsensors and -actuators, while the system emerges from a subsequent, mostly hybrid combination of components (bottom-up approach). In future MST developments, systems technologies for the linkage of individual functions will have to undergo intensive continued development to be able to keep abreast of increasing complexity and a higher level of integration.

The starting point for optimizing a microsystem is the applied technology requirements and that is why in the future greater importance will have to be attached to the "top-down" design and the tools needed for it including standardization of interfaces.

#### Systems Development Methods and Tools

Unlike conventional component design, the design of microsystems is typified by the need to take into account myriad physical, biological and chemical dimensions, different effective mechanisms, parasitic cross-sensitivities and technological parameters.

Currently available design tools that have thus far been developed basically for the demands of microelectronics are, as a rule, the only ones customized for dealing with the job step of microsystems design. For major areas of systems design, e.g., for the design of actuators and sensors, there presently is no universal design support. The same is true for the simulation of microsystems and their production processes that are receiving increasing importance because of the sizable development costs.

In upcoming years the task will have to be systematic study of this field and derivation of recommendations for consistent action so that in this area methods and tools will be available without delay for integrating microsystems components into complete microsystems. Continued progress in systems development will depend greatly on generalized use of computer-aided processes. Software developments will also have to be implemented that will allow a design using tools that can be used in mid-size industry (flexible software, software components, limited hardware costs).

Meeting these challenges will have to be the target of future research tasking. The following problems are among those that deserve consideration:

- study and selection of appropriate CAD framework systems for microsystems for the integration of different design programs; development of standardized user surfaces and interfaces
- development of open data structures for the storage of design and technology related data in an object-oriented database system
- linking existing and new design tools
- definition of interfaces for non-electronic components
- incorporation of the recycling and disposal problem (design for environment).

#### Signals Processing Concepts

Signals processing concepts determine how the "intelligence of microsystems" is distributed. Hence a decision has to be made regarding the extent to which signal pre-processing is to be arranged already for the individual sensor or how the information transfer is designed in individual systems and among a number of systems. Advances have already been realized in the interlinkage of microsensors of even very diverse technological character in bus systems.

Mastery of the increasing complexity of microsystems will, in the future, determine the application of new methods of signal processing and the control of those systems that go beyond the activities already carried out for the development of telecommunications and microelectronics. The assessment of optical sensor arrays, e.g.,

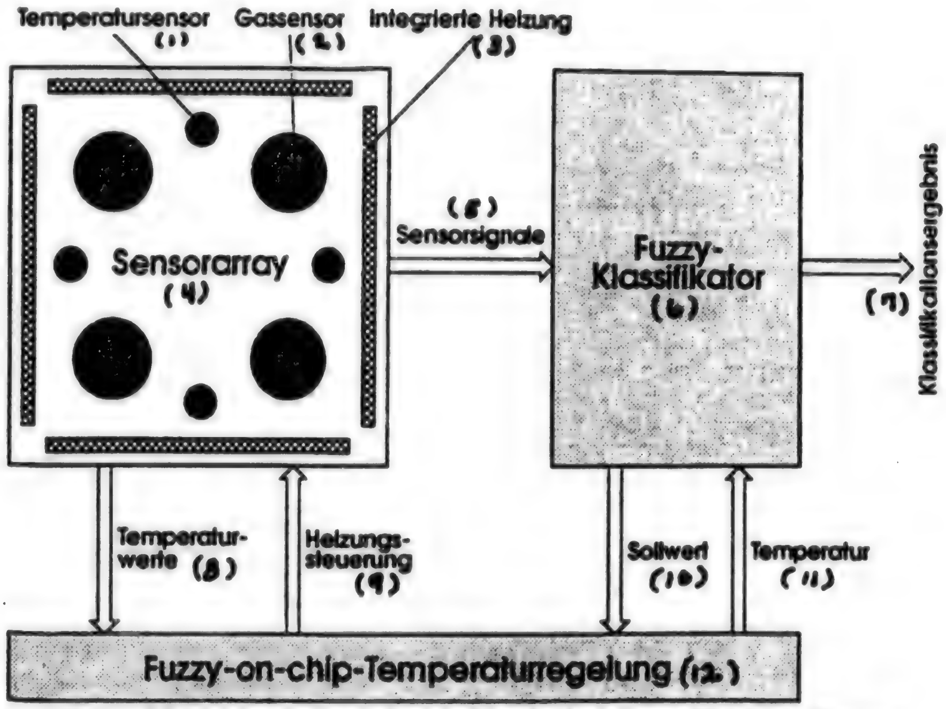


**Figure 4.1: Fuzzy microsystem for gas classification; source: FhG-IMS, Dresden**

Key: 1. Temperature sensor; 2. Gas sensor; 3. Integrated heating; 4. Sensor array; 5. Sensor signals; 6. Fuzzy classifier; 7. Classification of result; 8. Temperature values; 9. Heating control; 10. Index value; 11. Temperature; 12. Fuzzy-on-chip temperature control

requires real-time diagnosis by the on-board signal processing components even of incomplete or garbled signal quantities. The application of neural networks makes the fulfillment of such requirements optimally feasible as a result of exploiting the teachability of such structures. Further developments such as fuzzy logic, optical logic or molecular data storage offer promising approaches towards coming up with appropriate signals processing solutions with greater functionability of the sensor and actuator components.

**Testing and Diagnosis of Microsystems**

As early as the design of microsystems, appropriate self-testing and diagnosis components and the testing of underlying signal processing algorithms needs to be provided based on current processes in the development of microelectronic circuits (design for testability). To be able adequately to test the physical functions of the system, in complex microsystems, as needed, additional internal "test sensors" and "test actuators" have to be implemented. Via appropriate diagnostic interfaces those internal test components are to be linked with external diagnostic facilities so as to be able to test the functionality of the systems under actual conditions.

Simple test processes such as, e.g., measuring the input-output behavior, are available, but with increasingly denser integration and functionality they will no longer be adequate.

That is why, in the future, there will have to be a transition to uniform and cross-system strategies and signal processing concepts for the testing of microsystems. For validating systems functions in the development stage, if need be, mixed experimental arrangements of actually existing components and simulated models may be useful (hardware in the loop).

**Structural and Linkage Technologies**

Structural and linkage technology (AVT) includes all technologies and tools needed for integration in the smallest space. AVT enables the interlinking of microelectronic and non-electronic microcomponents into complete systems. It essentially helps determine the functionality, quality and economy of microsystems.

In recent years AVT has made decisive progress in terms of miniaturization, fail-safeness and the manageability of microsystems. It is tasked with tackling the technological requirements of systems integration for MST components and turns them into systems.

Critical chokepoints currently exist in the AVT sector for MST non-electronic components, for example, optical, mechanical, chemical or biological microcomponents. Besides the progressive development in the electronics sector, therefore, it will be necessary in upcoming years, above all, to introduce appropriate technological developments here and to supply suitable production technologies. This will also require basic developments having the following foci:

- providing new materials with defined macroscopic and microscopic properties (alloys, polymers, materials and film systems)
- study of phenomena that emerge when combining different materials and control of them (for example, interdiffusion processes, adhesiveness, thermomechanical interactions)
- soluble and nonsoluble linkage processes (microplug technology, memory alloys) not conclusively material
- availability of simulation tools
- availability of highly integrative production technologies (fine pitch), availability of equipment, reproducibility under production conditions and combinability of distinct levels of technology
- systems integration process based on biological models
- development of stacked integration technologies (stacked chips, stacked modules)
- ancillary studies on the reliability and degradation behavior of developed systems.

**Casings Technology**

In microelectronics and MST casings are tasked with protecting components and systems and concurrently bring about the integration of the system's environment. Whereas initially chip casing technology originally developed the chip with its connections and afterwards the appropriate casing, in MST it is no longer possible for the system's casing and the system itself to be viewed independently of one another. Casing in this instance constitutes an ineluctable component of an entire microsystem. In the process, the entire function of the microsystem is also being increasingly determined by the functional casing of the microsystem.

The importance of this theme was first recognized by the semiconductor industry. That is why the respective development projects are being carried out in the microelectronics sector. At present, chip casing technology is well advanced and affords solutions for myriad problems. Hence it is possible to equip individual chips as well as multi-chip modules with the most varied casings.

There is a requirement for inexpensive multifunctional materials that facilitate comprehensive design freedom in the design of microsystems, based on the properties of those materials. For instance, hermetically sealed casings having sensor windows and actuator throughputs are needed. Microsystems impose special requirements on casing technology since in them sensitive windows are directly exposed to the aggressive and/or corrosive action of chemical measurement media.

## 4.2 Microtechnologies

Microtechnologies lay the technological groundwork for the miniaturization and systems capability of the separate functions and components of the microsystem. The majority of MTs originated in microelectronics or conventional sensor/actuator technologies and these continue to be developed with a focus on the interests of MST.

**Micromechanics**

Mechanical components on the micrometer scale can be used as design elements (e.g., engravings, embedding structures, clamps, bending panels) for the development of microsystems, miniaturized functional sensor elements (e.g., sensor pressure membranes) or even as miniaturized actuator elements (micro-tweezers, microgears, microjoints, micropumps). Such microcomponents concurrently lay the essential groundwork for the development of more sophisticated microsystems such as micromachines. Based on lithographic processes for structural transfer, three-dimensional shaping can be realized using different micromechanical processes, e.g., through anisotropic etching of silicon, microelectroplating processes, laser processes or using Ion track Technology (ITT) that is still under basic development. With the LIGA process microstructural solids can be realized from a broad palette of materials such as metals, plastics and ceramics.

In the case of individual micromechanical technologies, research at the institutes has to demonstrate advanced results. Micromechanical pressure or acceleration sensors are already being offered as products. Clearly topping the list of materials currently being used is silicon, but other materials are becoming important, e.g., metals, plastics or glasses. In Europe so far surface micromechanics with its microelectronics-compatible processing procedures is hardly being pursued.

There are still significant problems in widely turning research results into additional industrial applications. The cost entailed is realizable for some firms only with difficulty because of the technological complexity. As a result, in this instance as in other microtechnologies, components and technologies as well as service and supplier product have to be made available by incorporating standardization activities concomitant with development for quality standards, subprocesses and "standard" components.

This includes the development of appropriate, cost-effective engineering of equipment for production. What

is more, in the future, basic studies need to be performed to be able to advance combination and integration with other technologies for the applicability of micromechanics. Examples of this are subprocesses for surface micromechanics, direct chip bonding at low temperatures, anisotropic dry-etching processes or the development of micromechanical processes for other materials.

**Integrated Optics**

The aim pursued in integrated optics is production of miniaturized optical components integrated in waveguide structures using planar technologies and "integration" of a number of such components on a common substrate.

In combination with other technologies those components are fine examples of microsystems that develop new fields of application, e.g., gas sensors for environmental technology.

The status of the development of integrated optics is assessed, depending on the materials employed, as follows: integrated optics in glass, as product examples demonstrate, have by now passed beyond the stage of basic industrial research. There is successful production of passive components like expanders, couplers, grid filters and spectrometers. Further activities are to be concentrated on the improvement of production technologies (implantation, exchange of ions) as well as the realization of new components (e.g., modulators) through additional film coatings.

At present silicon is still chiefly used as the underlying material in integrated optics. Familiar microelectronics technologies enable the structuring of highly precise guide structures for glass fibers and waveguide structures in film coatings.

With the possibility of being able to produce photodiodes, electronic components or optical waveguides in silicon, integrated optics will take on more importance in this context for future microsystems.

One field of research that is still quite recent entails the study of silicon structures that can be electrically excited to emit radiation. If luminescent silicon with an acceptable efficiency factor can be successfully developed, entirely fresh possibilities will open up for the integration of optical and electrical functions on a single silicon chip with far-reaching consequences for new sorts of sensor and systems designs.

$LiNbO_3$ is a well-researched "traditional" material for integrated optics on the basis of its outstanding electro-optical and electro-acoustical properties. A wealth of components such as wave guides, frequency doublers and mixers, parametric amplifiers and even optically pumped lasers have already been proposed.

Periodic system group III and V composite semiconductors are the materials that enable the broadest range of components for integrated optics to be realized.

The steadily increasing amounts of data in computer technology will render the application of integrated optical systems on a GaAs basis, e.g., for chip-chip and board-board coupling in connection with other integrated optical components especially interesting and necessary. That application will contribute significantly to further development of technologies for optically integrated microsystems.

Only in recent years have polymer materials been "rediscovered" for integrated optics. Polymer materials with excellent linear and nonlinear optical properties are currently available. Materials and processing technology make it possible to anticipate cost-effective components. R&D activities are primarily concentrated on the modification of materials' optical properties, processability and durability. Anticipated reduced production costs will smooth the way to broad application.

**Microoptics**

Generally, microsystems with optical functions also require optical imaging elements (mirror, lenses, filters, etc.). Microoptics involves the design and production process of such elements in miniaturized form.

Fiber optic or integrated optical components often are incapable of satisfying all the requirements so that in the case of optical microsystems there has to be a careful balancing act between monolithic integration (integrated optics) and hybrid development (fiber optics, integrated optics and conventional optical elements). For other applications only some optical functions are relevant, for which fully integrated solutions are too costly. Hence the increasingly pronounced use of microlenses, beam splitters and other components, preeminently at present in optical data technology but also in microsensors and actuators, for example, in the use of microlaser technology.

There are barriers to the employment of microoptical components in MST, above all, in production technologies that have not achieved full maturity and in the lack of structural and linkage technology for their integration in microsensors and -systems.

**Fiber Optics**

Fiber optics exploits guided optical and infrared radiation in beam waveguides. This enables benefiting from the advantages familiar from optical transmission technology: complete immunity against electromagnetic influences, extremely low attenuation values, great possibilities for miniaturization.

The primary fields of application for fiber optics in MST are fiber optic sensors and optical energy supply for microsystems. Presently, fiber optic solutions are characterized by a steady albeit gradual penetration in MST

since, because of the relatively high costs, they are used only where an above-average benefit can be expected or where other solutions are not feasible. With its considerable miniaturization fiber optics even now afford a noteworthy potential, above all, in medical technology, aerospace and industrial measurement technology.

There is a demand for the development of:

- specialty fibers and appropriate splicing processes
- cost-effective processes for mass production of more exact pin-and-socket connections
- bus compatibility of fiber optic sensors and components
- pathway-neutral coding/decoding processes
- efficient multiplex methods.

Other intriguing applications are being opened up through combination with other MST technologies, e.g., integrated optics or biosensors.

BMFT department 412's "Photonics" focus supports special problems in the area of integrated optics, microoptics and fiber optics..

**Film Technologies**

Epitaxial methods enable depositing different materials, e.g., semiconductors on one another with atomic level accuracy. This enables the realization of fresh designs for microelectronic components. Currently the best mastery of this is in III-V semiconductor materials systems (see also BMFT, department 412's "DFE [Delegation for State Energy Research] focus on II-V electronics).

The present status is typified by effective technologies and production concepts for microelectronics. As a result, significant miniaturization technologies are available that could develop, in modified form, further areas of MST application. This is how the processes for thin and thick film technology including the appropriate structuring processes are initially being brought to industrial maturity in semiconductor electronics for the films and film combinations needed there.

While thick-film technologies are already being extensively used for MST, thin-film technologies are still in the development or dissemination phase because of the difficult process technology. The demand for further development for MST is primarily directed at application-specific orientation and optimization of familiar processes and the inclusion of new materials and geometries. Specifically, the following objectives can presently be identified:

- double sided lithography and adaptation of lithographic technology to three dimensional micromechanical structures
- coating and microstructuring of new (e.g., bio-) materials
- combination of various materials in film systems (thin-film stacking technologies, additive technologies)
- modification of film coatings
- coating of non-planar substrates
- ultrathin insulator films
- spray-shielding for high-temperature applications.

The production and analysis of ultrasmooth surfaces, ultrathin films, lateral structures having structural dimensions of less than 100 nanometers [nm] and of materials and clusters having particle diameters of less than 100 nm are being conducted in the new research field of nanotechnologies. The application of the results of such research activities, e.g., on new thin-film sensors, will increasingly play a role in MST. Advances can be expected here, above all, as a result of further miniaturization, declining energy consumption by the components, new sensor and actuator principles bases on quantum effects in nanostructures and as a result of new materials properties.

## 4.3 Additional Sensor and Actuator Technologies

**Chemical Sensor Technologies**

Chemical sensors designate sensors that recognize any specific component in an unfamiliar medium and determine its concentration in the medium. One such component might, for instance, be the nitrogen oxide in the exhaust gas of a motor vehicle. Such sensors should react only to nitrogen oxide and not allow the measured value to be altered by other substances, i.e., they should not display any cross-sensitivities. They have to react with utmost speed, for instance, for optimum regulation of the combustion process or to able to point out problems to the driver. Besides the functional requirements, geometric dimensions and price are a major argument for or against widespread use of such sensors in miniaturized systems, e.g., in motor vehicles or in medical diagnostics. Other areas of application for chemical sensors include job monitoring, chemical process technology, environmental monitoring of water and air or processing of textiles where the necessity and appropriateness of the miniaturization is not given in each instance but instead is determined by the respective application.

Currently utilized chemical microsensors barely satisfy one of the above indicated criteria. The unsatisfactory results have taught us that successful results can be realized only with systems approaches. For example, on the one hand the chemical composition of the sensitive film of a sensor element is highly critical; but the physical processes on the surface and inside the sensitive film also determine its success.

Changes in the parameters can be realized by doping of the sensitive film or altering the working temperature.

Structural development and the thickness of the sensitive film quite significantly impact the result and particularly long term stability.

On the other hand, the past has shown that although sensor elements do have to be optimized, still, in virtually every instance, they are not suitable for practical application on their own. It is possible, e.g., to operate the sensors with direct or alternating current. The choice of frequency in alternating current makes it possible to vary the properties of the sensor and the sensitivities to specific substances. It may even become necessary to have preliminary signal processing work in tandem with a number of sensor elements having distinct cross-sensitivities in order to derive from the various signals unequivocal conclusions on the concentration of any specific component.

So far the results have been initial isolated solutions to relatively simple measurement tasks. Next, the suitability of various chemical compositions as sensitive materials will have to be studied. Many different principles underlie the development of chemical sensors. Here too a suitability study is indicated, especially because of the fact that, at present the emerging viewpoint is that quite excellent chemical sensors should be realizable through the use of a number of sensor elements having distinct sensor principles. This also includes the integration of additional sensors (e.g., for temperature, pressure) for a more certain interpretation of the measured results. Miniaturization technologies should be fine-tuned to focus on chemical sensors. The designs for preliminary signal processors are still not mature enough. In this context, too, activities are needed that take into account the latest know-how such as neural networks or fuzzy electronics.

Chemical microsensors will only become successful if systems technology is utilized. That is especially evident in the approaches currently being pursued for the development of microanalysis technology such as gas chromatographs on a wafer or complex chemical analysis systems that are still in the early stage of development.

**Biocomponents in MST**

The integration of functional biocomponent platforms such as protein molecules (e.g., enzymes or antibodies) or biological cells creates the possibility of realizing biosensors as greatly miniaturized individual modules or as microanalysis systems components. In this way it is possible to develop new fields of application for MST such as highly sensitive and selective measurement of the concentration of substances in fluid media as well as determination of biological parameters such as toxic or allergenic impact. By combining MST with the methodology of biotechnology a high potential for application of new biotechnological process on the level of individual biocomponents (living cells or receptor macromolecules) is the result.

Key technological problems arising from combining biocomponents with MST exist from the outset in working with them. That is why biosensors have so far only reached the experimental stage in the laboratory in the context of MST and MST solutions for biotechnological processes.

From a contemporary perspective, there is a demand for development on the following thematic foci:

- development of MST-compatible methods for the application, fixing and structuring of biocomponents
- characterization of the behavior of biocomponents on solid surfaces
- studies on bioinert/biocompatible materials
- development and qualification of suitable transducers for the physical and chemical conversion of the "biological" signal for further processing
- development of miniaturized functional components for the transport of probes and the processing of probes in analytical systems
- development of appropriate signal processing designs
- integration of functional components in systems solutions.

**Ceramics Technologies**

Ceramic materials consist of inorganic compounds that are subjected to a sintering process. Through the choice of composition and process control it is possible to fine tune mechanical, electrical and chemical properties over a wide range of modified and specific requirements.

Ceramic components have numerous fields of application in electrical engineering and electronics. They range from high-voltage insulators on the poles of cross-country power lines to chip carriers. Ceramic materials are also used for ferrites, piezoceramics, capacitors and lambda probes. In structural and linkage technology (AVT) for MST they have a wide field of application as substrates and casing materials. Those materials' critical properties for AVT are their stability and impermeability to gases plus their heat conducting properties and ability to be easily metallized.

In upcoming years sizable efforts will have to be undertaken to research basic ceramics materials for microoptical and micromechanical applications. Manageability and reproducibility of the production process will be central problems especially for AVT. Superconducting ceramic materials need to be viewed in terms of sensor properties. Ceramic films are available as composite elements for microsystem substrates and casings.

**Piezoelectric Actuators**

Piezoelectric actuators exploit the inverse piezoelectric effect. If an electric voltage is applied, e.g., to a piezoelectric crystal a change in geometry (change in length or thickness) occurs. This property facilitates the development of actuators.

So far piezoelectric actuators are being used only to a limited extent as servo components in an industrial application and this despite exceptional positioning properties in terms of displacement resolution and dynamics. One problem with piezoceramics is the limited change in length per application of electrical field intensity.

For example, field intensities on the order of one kilovolt [kV]/millimeter [mm] are required for a change in length of one per thousand. Hence piezoactuators are customarily fashioned from separate thin elements with stacked structuring. Currently, piezoelectric actuators are used as electronic actuators or actuating drives such as inchworm and ultrasonic motors in a limited number of pieces. The lion's share, by far, is for highly frequent applications such as sonar, ultrasound or acoustical "piezo-beepers" like the ones familiar on wrist watches.

With increasing demands for displacement resolution and dynamics for servo components, piezoelectric actuators are moving more and more into the viewing range of technological interest. Piezoactuators enable actuator energies in the kilo-Newton range with regulating distances of up to less than one half nanometers with high dynamics. This property foreordains piezoelectric systems for applications such as active vibration absorption. Piezoelectrical actuators possess a high efficiency factor. Virtually 50 percent, and nearly 90 percent through additional exploitation of capacitor stored energy, of input electric energy is capable of being converted directly into mechanical energy. The energy conversion is free of friction, slackness and wastage. Piezoelectric actuators possess systems technology advantages based on their small structural dimension (higher electromechanical efficiency factor), hybrid structuring and adaptive control, among other things, for position-controlled actuator operation. Proposed applications for microactuators even in association with stored-memory microsystems target valves and pumps, e.g., membrane pumps have a piezoelectric drive.

To realize broad market acceptance of piezoactuators, the following tasks need to be dealt with:

- enlarging the regulating distance in the mm range by means of hybrid drive systems (e.g., piezoceramic/hydraulic, electromagnetic actuators)
- appropriate standard systems components for the power supply
- inexpensive mass production (multilayer)
- low-voltage ceramics having enhanced properties
- increased magnetic transition temperature
- reduction of hysteresis
- improved heat conductivity and adhesive bondings
- development of miniaturized power amplifiers for the driving of (low-voltage) multilayer ceramics
- development of high-resolution capacitor measurement systems.

**Electromagneti Actuators**

In electromagnetic actuators electrical and magnetic energies are converted into one another. In the simplest case a mechanical switch serves as an energy actuator. Increasingly, energy actuation is done with electronic components (also see semiconductor power modules) that in turn are mechanically switched or can be operated under the control of hardware or software programming. From an MST viewpoint what is important here, above all, is the diminutive power range with its enormous diversity of types. In addition to rotary drives, linear drives too, in which regulating motions in the mm and cm range are frequently required, will also be dominated in the future by electromagnetic actuators. The demand for increased regulating accuracy for the µm and sub-µm range has led to the origination of drives that are quite costly from a mechanical point of view. In this case greater use of microelectronics coupled with miniaturized electromagnets and electric motors can lead to cost-effective systems having clearly improved regulating and positioning properties. Micropositionings of less than 100 nm with a concomitantly large regulating distance can be realized.

Development activities in the area of electromagnetic actuators include the following foci:

- microvalves for micrometering
- miniaturized electromagnetic actuating drives
- smart regulating designs taking into account internal and external failures
- micromotors
- electric motor rotary and linear drives on a pulse-motor basis
- effective electronics for smart control of pulse motors
- inexpensive high-resolution linear measuring systems for large regulating distances.

**Magnetostrictive Actuators**

Magnetostriction designates the alteration in the mechanical properties (primarily length) of a ferromagnetic material under the influence of an external magnetic field.

Highly magnetostrictive materials are produced by means of molten and powder metallurgical processes on the basis of intermetallic rare-earth/ferrous compounds.

Currently available materials allow for alterations in length of dl/l = 0.15-0.2 percent and can be produced for specific applications. Actuators are used in the form of regulating elements in applications that require quite sizable energies with high dynamics and short regulating distances entailing high positioning accuracy. Examples include sonar-transducers, valve controls and regulating elements in machinery. Potential fields of application include micropositionings, linear motors, rotary drives, servo-valves, injection valves in vehicles and active vibration absorption. There are still no products currently available on the market. The first concrete developments are concentrated on injection valves and active vibration absorbers.

At present the basic groundwork for widespread application of magnetostrictive actuators is missing. Many problems remain unresolved, especially for the integration of electronics, mechanics and materials development, e.g.:

- At present the Terphenol-D alloy is being produced in only small quantities. Widespread application will require the availability of more cost-effective production processes.
- It is also necessary for the mechanical materials parameters to be improved. This would enable a cutting process to realize different structural forms.
- There are still no suitable tools for computation, simulation and design of actuators.
- There are deficiencies in the design of components and the simulation of the entire system for control and systems integration of actuators.

**Shaped Memory Alloys**

Shaped-memory alloys are characterized by three special effects: the shaped-memory effect, superelasticity and high attenuation capability. If a shaped-memory alloy is permanently shaped at temperatures below a defined critical temperature, it is capable, when heated above that critical temperature, of remembering its original shape and recovering it.

Shaped-memory alloys are primarily used in joining elements and actuators.

While joining elements have been used for decades now, e.g., in the form of pipe joints, the possibilities in the field of actuators have been systematically studied only for a few years. The foci here include use as a thermal actuator having an integrated sensor function and the realization of sophisticated forms of movements in a minimum area. By fully exploiting the superelastic effect in endoscopes, use in medical technology is emerging increasingly into the limelight.

If shaped-memory alloys are to be able to be incorporated more extensively in microactuators in the future, the following constraining factors remain to be dealt with:

- Relatively slight paybacks are realized from the production of the alloys meaning that the prices for the alloys are correspondingly high.
- The stability of the shaped-memory effect currently limits the possible number of cycles.
- The maximum useful temperature of the most effective alloys is currently approximately 100°C.
- Improvement of the dynamic behavior, especially of the cool-down behavior through active cooling or appropriate composite structures
- There are no appropriate control processes for relatively accurate positionings using actuators on the basis of shaped-memory alloys
- Models need to be developed for the design and simulation of the behavior of corresponding actuators
- Hybrid structures and composite materials involving components or films from shaped-memory alloys appear to be particularly suitable for applications in the field of actuators although they are scarcely being explored.

**Semiconductor Power Modules**

Semiconductor power components are used to control and regulate electrical outputs. The adaptation of microelectronics technologies to the special demands of power semiconductors as well as the introduction of novel assembly designs has made it possible in recent years to develop modern cut-off power components. The basic advantages of such new components as compared with conventional thyristors include reduced circuit complexity, improved dynamic ratings and higher maximum operating frequencies with a concomitant reduction in space requirement.

Such components enable the development of miniaturized smart power modules. Depending on their respective output ranges, such modules constitute a monolithic or hybrid integration of power chip, control circuit and logic and a stylized structural and interlinkage technology and are part of what are currently the most innovative fields in industrial electronics.

Based on a current projection, the R&D foci in upcoming years will include the following themes:

- development of new insulator technologies that can be realized even on a production scale for monolithic integration even in the mid-voltage range (several hundred volts), e.g., wafer bondings

- development of direct current actuators having a high efficiency factor at voltages of several volts
- improvement of EMV [electromagnetic compatibility]
- further decentralization of intelligence through integration of microprocessors in smart power modules for autonomous status monitoring
- development and enhanced use of simulation tools for effective electronic systems involving standardized user interfaces (SME manageability).

In the BMFT, department 412, "Silicon Carbide Electronics" [SiC] focus, basic technological development of SiC semiconductor material is supported.

**Fluid Technologies**

What distinguishes fluid technology drives is the simple, risk-free and environmentally-friendly origination of motions and energies in virtually any shape and size. Because of their high power density they also hold special importance for machine building. Their symbiosis with microelectronics has enabled further enhancement of the effective capability of fluid technology drives. Smart regulators having adaptive algorithms, for instance, are presently capable of adapting themselves to varying operating conditions.

Because of requirements especially from the automation technology sector development all the way to smart subsystems will be necessary in the future. The reversible and irreversible alterations in operational behavior occurring in fluid technology drives will likewise have to be taken into account such as the load rigidity that remains unsatisfactory by comparison with rival technologies (e.g., piezoactuators) and manageability by fluid technology producers who are heavily oriented to mid-size industry.

Because of high power density fluid technology is also a sure ringer for use in microsystems. Potential applications range from micrometering systems for medical materials all the way up to fully miniaturized analytical systems, e.g., for environmental measurement technology. For fluid technology to be used in microsystems appropriate components, e.g., micromechanical valves will have to be made available in th future and suitable systems technologies formulated tc integrate them with sensors and signal processing.

## 5 Appendix

### 5.1 Finance Plan

The existing (1994-1999) MST support program builds on the earlier (1990-1993)[21] MST support focus which, in turn, took into account the experiences from the microperipherals[22] support focus. Since combined projects have a multiyear running time, it turns out that a portion of the funding slated by the BMFT for 1990-1993 as a whole was still needed for the completion of the microperipherals support focus. Added to this was the funding needed to continue microperipherals projects from the NBL that had still been initiated by the GDR'S Ministry for Research and Technology. Table 5.1 below displays the allocation of project support funding over the years and for the separate support activities. The figures cited for 1995 ff. are in line with the finance planning (FinPL). Finance planning data is subject to the proviso of the German parliament's annual budget resolutions. No finance planning exists yet for 1998 and 1999. For the years 2000 ff., funding is slated for completion of projects authorized during the period of the support program.

| Kap. 3004, Tit. 68346 (1) (2) | 1990 (Ist)(3) | 1991 (Ist)(3) | 1992 (Ist)(3) | 1993 (Ist)(3) | 1994 (Soll)(4) | 1995 (FinPl)(5) | 1996 (FinPl)(5) | 1997 (FinPl)(5) |
|---|---|---|---|---|---|---|---|---|
| **Ind.-spez. Förderung (6)** | | | | | | | | |
| - Mikroperipherik (7) | 0,3 | 0,0 | 0,1 | 0,1 | 0,0 | 0,0 | 0,0 | 0,0 |
| - Mikrosystemtechnik (8) | 4,1 | 22,1 | 32,6 | 21,6 | 30,0 | 4,0 | 2,0 | 0,0 |
| **Verbundförderung (9)** | | | | | | | | |
| - Mikroperipherik (7) | 47,0 | 31,5 | 20,7 | 7,1 | 0,0 | 0,0 | 0,0 | 0,0 |
| - Mikroperipherik NBL[2] (10) | 0,0 | 19,7 | 3,1 | 1,6 | 0,5 | 0,0 | 0,0 | 0,0 |
| - Mikrosystemtechnik (8) | 1,1 | 10,6 | 28,6 | 52,5 | 63,2 | 69,4 | 66,2 | 63,0 |
| **Technologietransferförderung und Querschnittsaufgaben (11)** | | | | | | | | |
| - Mikroperipherik (7) | 2,3 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| - Mikrosystemtechnik (8) | 5,9 | 9,6 | 6,7 | 5,9 | 0,7 | 0,0 | 0,0 | 0,0 |
| **Förderung der industriellen Diffusion und Technikfolgenabschätzung, Wissenschaftskooperation (12)** | | | | | | | | |
| - Mikrosystemtechnik (8) | 0,0 | 0,0 | 0,0 | 0,0 | 2,6 | 3,5 | 3,6 | 3,7 |
| **Projektstabskosten (13)** | 4,1 | 4,5 | 4,8 | 4,8 | 5,0 | 5,1 | 5,2 | 5,3 |
| Summen (14) | 64,8 | 98,0 | 96,6 | 93,6 | 102,0 | 82,0 | 77,0 | 72,0 |

**Table 5.1: Federal funding for project support in millions of DM**

Key: 1. Chapter; 2. Title; 3. Actual; 4. Projected; 5. Financial plan; 6. Indirect-specific support; 7. Microperipherals; 8. MST; 9. Combined support; 10. Microperipherals in the NBL; 11. Support for technology transfer and cross-tasking; 12. Support for industrial dissemination and TA, scientific cooperation; 13. Project administration costs; 14. Totals

## 5.2 Tips for Applicants and Addresses

This booklet on the existing program provides a complete overview of the BMFT's support activities bearing on MST. Applications for industrial combined projects, preliminary scientific projects under the existing "MST" program and the "Innovation Support" program should be addressed to:

VDI/VDE-Technology Center for Information Technology GmbH [VDI/VDE-IT] Rheinstr. 10 B, 14513 Teltow, Tel.: 03328/435-0.

The VDI/VDE-IT also support the introduction of MST in commercial practice.

Applications for support for international scientific cooperation with foreign countries (cf. section 3.5) should be forwarded to:

German Academic Exchange Service (DAAD) Department 316, Kennedyallee 50, 53175 Bonn, Tel.: 0228/882-0.

Applications for an R&D loan for small firms should be submitted with KfW application Form 141 600 and statistical insert 141 661 via a credit institute to the

Credit Bank for Redevelopment [KfW] Palmengartenstr. 5-9, 60325 Frankfurt, Tel.: 069/7431-0.

Under the experimental model "Share Capital for Fledgling Technological Enterprises" (BJTU), applications for refinancing should be submitted likewise via a capital investor to the KfW. Applications for participation should be submitted jointly with the co-investor to the

Technology Participation Society mbH of the German Equalization Bank (TBG) Wielandstr. 4, 53170 Bonn, Tel.: 0228/9312236

Applications for a subsidy for risky R&D projects that are to be carried out through transnational or national cooperation between at least two firms, plus applications for commissioned R&D should be forwarded on official forms to:

"Otto von Guericke" e.V. Association of Industrial Research Organizations (AiF) Tschaikowskistr. 49, 13156 Berlin, Tel.: 030/482 6649

Addresses for other federal support program project sponsors (cf. section 2.3.2):

German Aerospace Research Institute (DLR) Project sponsor for "Information Technology" - P.O. Box 906058, Linder Hoehe, 51140 Cologne, Tel.: 022203/6012840 - Rudower Chausse 5 12489 Berlin Tel.: 030/6775091

Project sponsor for "Work and Technology" Suedstr. 125, 53175 Bonn, Tel.: 0228/38210

Juelich Research Center GmbH (KFA) BEO, P.O. Box 1913, 52425 Juelich, Tel.: 02461/612714

VDI/VDE-Technology Center (VDI/VDE-TZ) Physical Technologies Graf-Recke-Str. 84, 40002 Duesseldorf, Tel.: 0211/62140

### 5.3 Publications Dealing with Microsystems Technology

*May Be Ordered from VDI/VDE-IT, Rheinstr. 10 B, 14513 Teltow:*

MST Studies, 1990, 13 volumes, each nominally priced at DM60.00

Volume 1: Possibilities and Ranges for Piezoceramic Actuator Applications

Volume 2: Application-Specific Smart Semiconductor Power Modules

Volume 3: Possibilities and Ranges for Applications of Magnetostrictive Materials

Volume 4: Technological Equipment for the Production of Silicon- and Quartz-based Micromechanical Components

Volume 5: Micromechanics—Components and Suppliers of Services

Volume 6: Ceramics for Chemical Sensors

Volume 7: Integrated Optics—Potential for Mid-Size Producers and Consumers of Microsystems

Volume 8: Status and Development of Wire Bonding Technology

Volume 9: Microsystems Technology in the Former GDR

Volume 10: Electrorheological Fluidities

Volume 11: Systems and Signal Processing Designs for Microsystems Technology

Volume 12: Application-Specific Integrated Circuits [ASIC]

Volume 13: Tools and Technologies for the Development of Electronic Circuits

*Final Reports on Combined Projects and Succinct Studies, 1993*

Volume 1: Actuators of Microstructured Silicon for Pneumatic and Hydraulic Applications, DM125.00

Volume 2: Structural and Linkage Technology for Fiber and Integrated Optical Sensors, DM125.00

Volume 3: Basic Studies of Nonlinear Effects in Beam Waveguides Modeled After a Brillouin Ring Laser for Microsystems, DM125.00

Volume 4: Development of a CMOS-Compatible Integral Process for the Production of Silicon-Based Integrated Optical Circuits, DM75.00

Volume 5: Injection Molding Technologies Using Polymer Materials: Potential for Application in Microsystems Technology, DM75.00

Volume 6: Basic Developments for the Networking Capability of a Family of Smart Sensors/Actuators in Microsystems technology (GENIS), DM125.00

Field Buses in the Sensors and Actuators Sector—Comparative Studies of Field Buses for Sensor and Actuator Systems That Are Available and Under Development, 1990, 91 pages [pp.], nominal price of DM60.00

The Microsystems Technology Support Focus and Its Origin—Ex Ante Assessment, 1990

Microsystems Technology Support Focus—Assessment and Evaluation of the Indirect-Specific Measure. Preliminary Empirical Report, 1991, 70 pp., nominal price of DM15.00

Services Offered by Institutes in Microsystems Technology, 1991, 242 pp., nominal price of DM100.00

Catalog for Advanced Training in Microsystems Technology, 1991, 457 pp., nominal price of DM50.00

Proceedings ACTUATOR 92, 3rd International Conference on New Actuators, 1992, 269 pp., nominal price of DM250.00

Technology Transfer—Survey of Current Projects on Technology Transfer Under the Microsystems Technology Support Focus, 1992, 58 pp.

Microsystems Technology Services Center, 1992, 51 pp., nominal price of DM15.00

Microsystems Technology Support Focus—Assessment and Evaluation of Combined Activity. Second Empirical Report, 1993, 200 pp., nominal price of DM39.00

Microsystems Technology's Regional Potential, 1993, 38 pp.

Specialized Supplement on "MICROPERIPHERALS/MICROSYSTEMS TECHNOLOGY," for the years 1990-1993, nominal cost of each is DM60.00

MST News—International Activities in Microsystem Technology, ca. thrice yearly, free

"Who Is Who in MST"; Database Extracts on Diskette

International MST Events, ca. twice yearly, free

*May Be Ordered from IBI GmbH, Kaiserstrasse 46, 40479 Duesseldorf:*

Microsystems Technologies—Status and Development, VDI-Verlag 1993, DM98.00

Management of R&D Cooperative Activities in High-Tech Fields, 100 pp., nominal price of DM59.00

Microsystems Technology Who Is Who Transfer Atlas, 550 pp., nominal price of DM98.00

Analysis and Assessment of R&D Transfer Landscape in Microsystems Technology, 40 pp., nominal price of DM39.00

Patent Analysis for Chemical Sensors, 30 pp., nominal price of DM15.00

*May Be Ordered from GIB, Luetzowstr. 102-104, 10785 Berlin:*

The Industrial Spread of Microsystems Technology, 73 pp., nominal price of DM79.00

*Can Be Gotten at Bookstores:*

Reichl, H. (ed.): Micro System Technologies 90, Springer-Verlag, 1990

Krahn, R./Reichl, H. (eds.): Micro System Technologies 91, VDE-Verlag, 1991

Reichl, H. (ed.): Micro System Technologies 92, VDE-Verlag, 1992

Product Innovation in Sensors. Technology, Management, Government Support, ed.: VDI/VDE-IT, Sigma-Verlag, 1991

Gronau, M. (ed.): Technologies for Microsystems, VDI-Verlag, 1993

Micro System Technologies 90—Users Forum, ed.: VDI/VDE-IT, VDE-Verlag, 1990

**Footnotes:**

1. Cf. GIB and VDI/VDE-IT: The Industrial Spread of Microsystems Technology, Berlin, 1993, and: GIB and VDI/VDE-IT: MST's Market Potential (unpublished draft).
2. Cf. Albert Ludwigs University, Freiburg: Department Design for Applied Sciences Having MST and Computer Courses, 1992.
3. Parliamentary document 11/8271.
4. As of October 1990 it was possible for participants from the NBL to participate.
5. Eschenbach et al.: Assessment and Evaluation of Combined Activity, Second Experiential Report, Berlin, 1993.
6. Hafkesbrink, et al.: Technologies for Microsystems—Status and Development, Duesseldorf, 1993.
7. Firms from the NBL were able to participate only from October 1990 until the end of the deadline for application (march 1991); in that period 156 projects were submitted from the original laender.
8. Cf. GIB: Innovative Management in MST (unpublished draft).
9. Cf. GIB: Potential and Demands of MST (unpublished draft).
10. Cf. GIB: Innovative Management in MST (unpublished draft).
11. Cf. VDI/VDE-IT (editor [ed.]): MST Service Supplier Atlas, Berlin, 1991; also, IBI (ed.): MST Who Is Who Transfer Atlas, Duesseldorf, 1993; Hafkesbrink and Horst: Assessment and Evaluation of Technological Activities Under Support for Innovation, Duesseldorf, 1992.
12. Fraunhofer Institute for Systems Technology and Innovative Research (ed.). Technology at the Start of the Twenty-First Century—Discussion Paper, March 1993, Karlsruhe.
13. Cf. Grupp, H.; Schmoch, U.: Scientific Linkage of Technology, Heidelberg, 1992, pages [pp] 125, 138 and following [ff].
14. Cf. GIB and VDI/VDE-IT: The Industrial Spread of MST, Berlin, 1993.
15. Under the EU's common framework for official R&D assistance, attachment I, the following restrictions apply: industrial basic research is defined as autonomous theoretical or experimental work aimed at acquiring new or improved understanding of the laws of science and technology including their application to an industrial sector or the activities of a specific firm. Applied research includes research or experimental activities on the basis of the results of industrial basic research for the purpose of acquiring new insights to facilitate the realization of specific, practical goals such as the creation of new products, production processes or services. As a rule, it can be said that it terminates with the creation of an initial prototype. Development includes activities on the basis of applied research aimed at the introduction of new or significantly improved products, production processes or services all the way up to—but not including—industrial application and commercial exploitation. This stage typically includes pilot and demonstration projects as well as the additionally necessary development activity that ultimately leads to an aggregation of data that allow the start of production (official gazette of the European Community Nr. C83/2 of 11 April 1986).

16. Under the EU's common framework for official assistance to SMEs, a firm is defined as "SME" if

- the labor force does not exceed 250

- either realizes an annual turnover of no more than DM40 million or - realizes a total balance of no more than DM20 million

- finds itself in possession at most of 25 percent of one or more firms not satisfying that definition (exception: public stock companies, risk capital companies and—in so far as no supervision is exercised—institutional investors).

All three requirements have to be fulfilled concurrently, that is, a firm is only considered "SME" if it demonstrates the required autonomy, meets the prescribed employment figure and does not exceed at least one of the limiting values for annual turnover or total balance. (Official gazette of the EC, Nr. C 213/2 of 19 August 1992).

17 Cf. Soete: Understanding of the Diffusion Process, in DG [Directorate General] XIII: Innovation in the Nineties, Brussels, June 22/23, 1992.

18. Cf. Hafkesbrink: Evaluation of the Support for Precompetitive R&D Cooperative Activities as Exemplified in MST Combined Projects, Duesseldorf, 1992.

19. Cf. GIB and VDI/VDE-IT: The Industrial Spread of MST, Berlin, 1993.

20. Cf. GIB: Managing for Innovation in MST (unpublished draft).

21. Cf. BMFT: MST, Second Expanded Edition, Bonn, 1992.

22. Cf. BMFT: 1985-1989 Microperipherals Support Focus, Bonn, 1985.

23. New laender microperipherals projects as an adjunct to activities that had still been supported by the GDR's Ministry of Research and Technology.

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